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Floristic reconnaissance of the northern portion of the Gregory National Park, Northern Territory, Australia

D M J S Bowman, B A Wilson & P L Wilson

Conservation Commission of the Northern Territory PO Box 38496, Winnellie, N T 5789

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Abstract

A floristic reconnaissance of two areas in the northern portion of the Gregory National Park revealed a range of distinct vegetation types. Numerical classification was used to determine 13 plant communities from an area near Victoria River Crossing and 10 communities from Bullita homestead area. These communites were shown to form significant associations with landform and geology. The latter were found to be closely related, as the topography of the area is strongly controlled by the erosion of Adelaidean sediments, some of which have been capped by Lower Cambrian basalts. The plant communities are best grouped within landform complexes, which include: riverine, plain, undulating terrain, mesa plateau and slope, and plateau/hill rims. These complexes can be subdivided by substrate material and surface soil texture. Vegetation maps at a scale of 1:100 000 were unable to differentiate all the communities due to the complex micro-pattern of some vegetation types.

The complete list of species recorded at the Victoria River and Bullita areas was found to be closely related to the nearby Keep River National Park, but to be poorly related to the Bungle Bungle National Park area in WA. Other areas of sandstone in the northern coastal region of the NT were found to be poorly related to Gregory. It is suggested that these similarities are associated with rainfall and the relative development of sandstone canyons, which act as refugia for mesic plant species. A major management problem of Gregory National Park relates to feral animals and their suspected association with soil erosion and the spread of exotic plants.

Introduction

A basic requirement of nature conservation is an appreciation of the uniqueness and representativeness of nature reserves. Vast areas of the Northern Territory are botanically poorly explored. This lack of basic data hampers conclusions as to the conservation value of reserves in protecting rare or threatened vegetation. One approach to overcome this problem is to produce small scale vegetation maps. This method has the advantage of providing an overview of major vegetation formations, but suffers the disadvantage of treating the flora superficially. Another approach is to analyse biogeographic patterns of Herbarium records (Dunlop & Bowman 1986). The utility of this method however, is dependent upon the thoroughness of past plant collecting.

This paper reports the results of a botanical reconnaissance of Gregory National Park, in which two small areas assessed to represent major land types within the park, were studied in detail. Fieldwork was undertaken to simultaneously ground truth large scale vegetation maps, record data for phytosociological analysis and collect specimens of all vascular plant species for preservation in the Northern Territory Herbarium. Phytosociological analyses were conducted to provide land managers with basic ecological data, and enable comparison with vegetation surveys of other areas in northern Australia, enabling the flora of the park to be placed into a regional context.

The **Appendix** is a Supplementary Publication and is not printed with the paper. Copies are lodged with the Society's Library (c/- Western Australian Museum, Perth WA 6000) and with the National Library of Australia (Manuscript Section, Parkes Place, Barton ACT 2600). Photocopies may be obtained from either institution upon payment of a fee.

Table 1

Climatic data for Victoria River Downs and Timber Creek.

A = mean precipitation (mm); **B** = mean number of rain days; **C** = mean daily maximum temperature (°C); **D** = mean daily minimum temperature (°C).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Victoria River Downs													
A	145	142	106	19	6	2	3	1	4	17	61	112	618
B	11	10	8	2	1	0	0	0	1	2	6	9	50
C	37.0	35.5	34.7	34.7	31.7	29.6	29.0	32.3	35.5	37.7	38.3	38.1	34.5
D	25.0	23.9	23.2	19.8	16.3	12.2	10.8	14.1	18.0	22.0	23.5	24.2	19.8
Timber Creek													
A	197	201	157	25	5	2	1	0.4	4	27	66	128	813
B	12	12	9	2	1	0	0	0	1	3	6	9	55
C&D N/A													

Regional environment

Climate

The climate is monsoonal with five months of summer rains (Table 1). The total annual rainfall (618—813 mm) is between one half to one third of that received at Darwin, and the number of raindays is one half of those recorded for the northern capital. Summer mean maximum daily temperature and winter minimum daily air temperature are more extreme than the north coast of the N T.

Geology

Gregory National Park is situated in the Victoria River Basin (Sweet 1977). During the early Adelaidean, cycles of marine deposition and subsequent uplift and erosion produced sequences of sandstone, siltstone and carbonate rocks (Sweet 1972). Frequent faulting fractured these sediments. Lower Cambrian basalt was extruded across parts of the landscape, with deep lateritization occuring during the Tertiary (Sweet 1972). Uplift and erosion since the late Tertiary have exposed older rocks and produced a landscape of wide plains with resistant sediments forming plateaux and mesas, some with a remnant lateritized cap.

Soils

Soils of the park are generally related to lithology and topographic position. Much of the area consists of steep tablelands and hills with shallow immature skeletal soils (Stewart 1970). Deep soils are confined to gentle lower slopes, where red and yellow earths are common with poorly drained lower slopes possessing cracking clays. Alluvial soils, invariably cracking clays, have developed on river flats.

Methods

Landsat imagery at a scale of 1:250 000 was visually interpreted to produce a map of gross land types (Fig. 1). From this interpretation, areas of approximately 25 by 25 km, near the Victoria River Crossing and the Bullita homestead, which were assessed as being representative of environments within the park and important for public access, were selected for intensive study. Photopatterns of the two areas were delineated on 1:80 000 scale, 1968, black and white aerial photographs and 1:100 000 maps compiled.

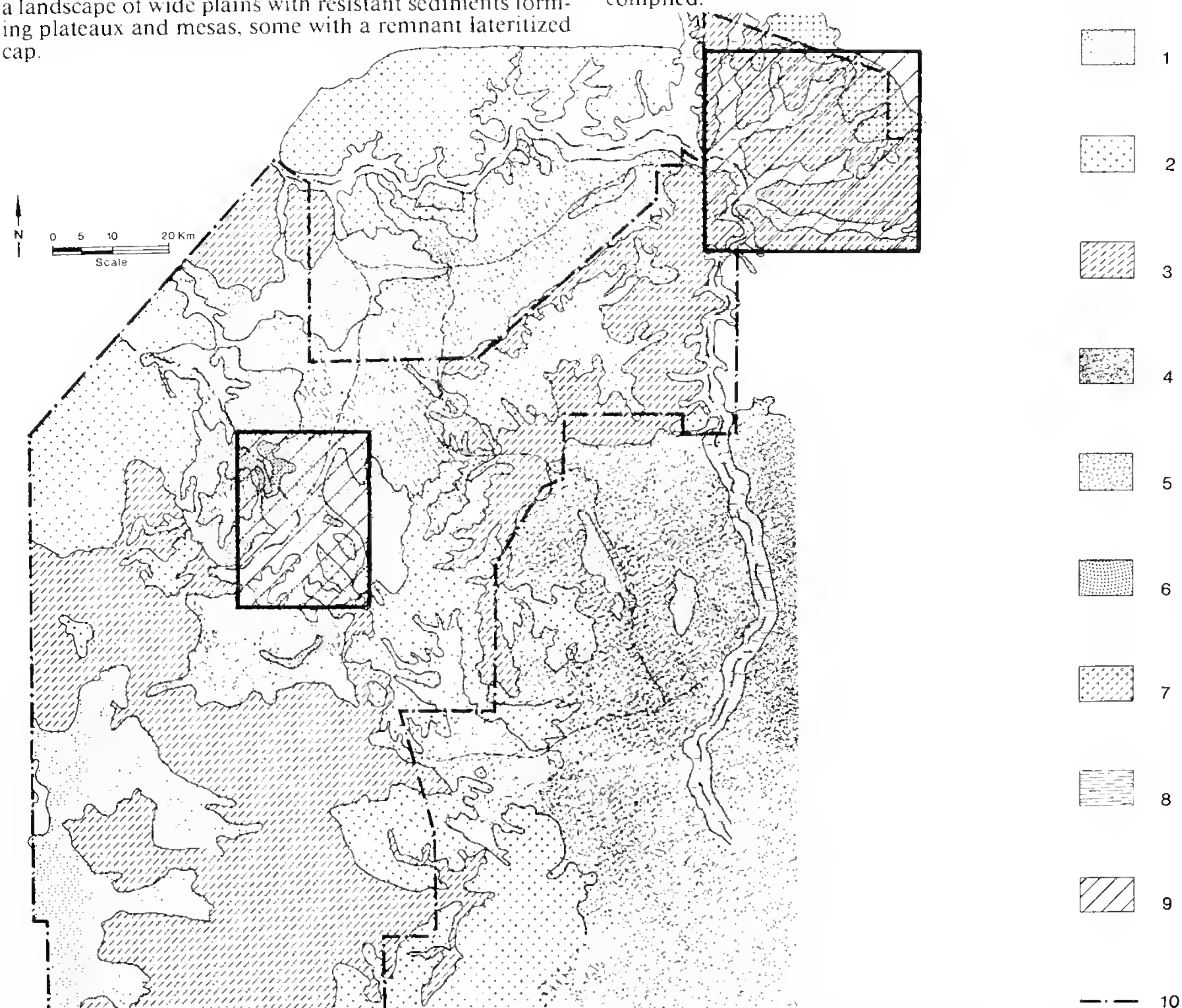

Figure 1 Map of major land types within the environs of the proposed Gregory National Park. (For location of this area see Fig. 7). The map is based on 1:250 000 satelite imagery. Ground truthing is restricted to the two study areas in the northern portion of the park. Mapping units correspond to the following environments: **1** Lateritic plateaux; **2** Sandstone plateaux; **3** Sandstone hills and dissected plateaux; **4** Limestone plains; **5** Limestone hills; **6** Dissected limestone; **7** Basalt plains and plateaux; **8** Floodplains; **9** Survey areas; **10** Park boundary.

A total of 327, 10 by 10 m quadrats were placed (181 at Victoria River and 146 at Bullita) within identified photopatterns, using a combination of systematic sampling of tracks, field traverse and helicopter landings during late February and early March 1986. The presence of all vascular plant species was noted in each quadrat. The structure of surrounding vegetation was classified according to the scheme of Walker & Hopkins (1986) and subsequently converted to the scheme of Specht (1981). The topographic position of quadrats was classified as either: mesa top, mesa/hill rim, mesa sideslope, mesa gully, hilltop, hill sideslope, plain, permanent watercourse, ephemeral watercourse or drainage basin. Rock outcrop was noted as either sandstone, limestone, sandstone/limestone mix, basalt, laterite or covered with alluvial deposits. The percent cover of rock, gravel and bare ground was noted. Surface soil texture was classified as either sand, loam or silt/clay.

Data analysis

Floristic and environmental data are stored on the ecological data base system ECOPAK (Minchin 1986). Victoria River and Bullita data sets were classified separately. Before analysis, species that occurred in less than three quadrats were deleted from the matrix. The presence/absence floristic data for each site were subjected to an agglomerative classification using the UPGMA sorting strategy after calculating a Bray-Curtis similarity matrix using the Numerical Taxonomy Package NTP (Belbin *et al.* 1985). The classification was imposed on the relatively continuous variation across the communities. As there are no defined stopping rules in classification, the level of truncation, which was not consistent across the dendrograms, was determined subjectively after careful inspection with lists of species memberships. The association between the non-parametric environmental variables and the floristic groups was tested for departure from randomness by Chi-square analysis.

The centroids of the resulting 23 floristic groups were ordinated by Detrended Correspondence Analysis (Hill & Gauch 1980). Because of limitations in computer space, only those species that ocurred in more than 5 groups (245) were used in the ordination.

Community definitions

Thirteen floristic groups were recognized at Victoria River (Fig. 2) and 10 floristic groups were recognized at Bullita (Fig. 3). Structural classification (following Specht 1981) and dominant species for the upper, mid and lower strata for each group, are shown in Tables 2 & 3.

A total of 517 species was encountered in the survey. Their percent frequency occurrence by classification group is indicated in the Appendix.

Table 2

Structural classification (Specht 1981) and dominant species for upper, mid and lower strata for floristic groups at Victoria River

Group No	Upper stratum	Middle stratum	Lower stratum
1	Low open-woodland of *Eucalyptus dichromophloia, E. ferruginea, E. miniata.*	Shrubland of *Acacia lacceata* and *Grevillea* spp.	Grassland of *Plectrachne pungens* and *Eriachne ciliata.*
2	Low woodland of *E. dichromophloia* and *Erythrophleum chlorostachys.*	Shrubland of *Petalostigma quadriloculare, Cochlospermum fraseri* and *Calytrix exstipulata.*	Grassland of *Plectrachne pungens* and *Eriachne ciliata.*
3	Woodland of *E. miniata* with subdominant *Terminalia latipes* and *Owenia vernicosa.*	Shrubland of *Buchanania obovata, Templetonia hookeri* and *Acacia* spp.	Open-grassland of *Plectrachne pungens* and *Fimbristylis pauciflora*
4	Forest of *Livistona* sp. nova *Pouteria sericea, Ficus* spp. and *Vitex glabrata.*		Sparse ferns and *Cyperaceae spp.*
5	Woodland of *E. tectifica* and *Lysiphyllum cunninghamii.*	Shrubland of *Ampelocissus acetosa* and *Hakea arborescens.*	Grassland of *Heteropogon contortus Sorghum plumosum* and *Schima nervosum.*
6	Low open-woodland of *E. tectifica* with co-dominant *Erythrophleum chlorostachys.*		Grassland of *Schima nervosum. Themeda avenacea* and *Eriachne ciliata.*
7	Open-woodland of *E. tectifica* and *E. terminalis*	Open-shrubland of *Atalaya hemiglauca* and *Grewia retusifolia.*	Grassland of *Schima nervosum Dichanthium fecundum* and *Chrysopogon fallax.*
8	Low woodland of *Erythrophleum chlorostachys, E. tectifica* and *E. confertiflora.*	Open-shrubland of *Atalaya hemiglauca* and *Grewia retusifolia.*	Open-grass/herbland of *Plectrachne pungens, Tacca leontopetaloides* and Fabaceae spp.
9	Open-forest of *Ziziphus quadrilocularis, Strychnos lucida* and *Celtis philippinensis* with emergent *E. confertiflora.*		Sparse *Commelina ensifolia* and *Passiflora foetida.*
10	Low woodland of *Melaleuca argentea, Lophostemon grandiflorus, Terminalia platyptera* and *Pandanus aquaticus.*		
11	Woodland of *E. camaldulensis, Nauclea orientalis* and *Ficus coronulata.*		Open-grassland of *Echinochloa colona* and *Cynodon dactylon.*
12	Closed-forest of *Syzygium angophoroides, Livistona* sp nova and *Ficus* spp.		Open-sedge/herbland.
13	Low closed-forest of *Melaleuca symphyocarpa* with emergent *Melaleuca leucadendra.*		Sparse cover of Cyperaceae spp.

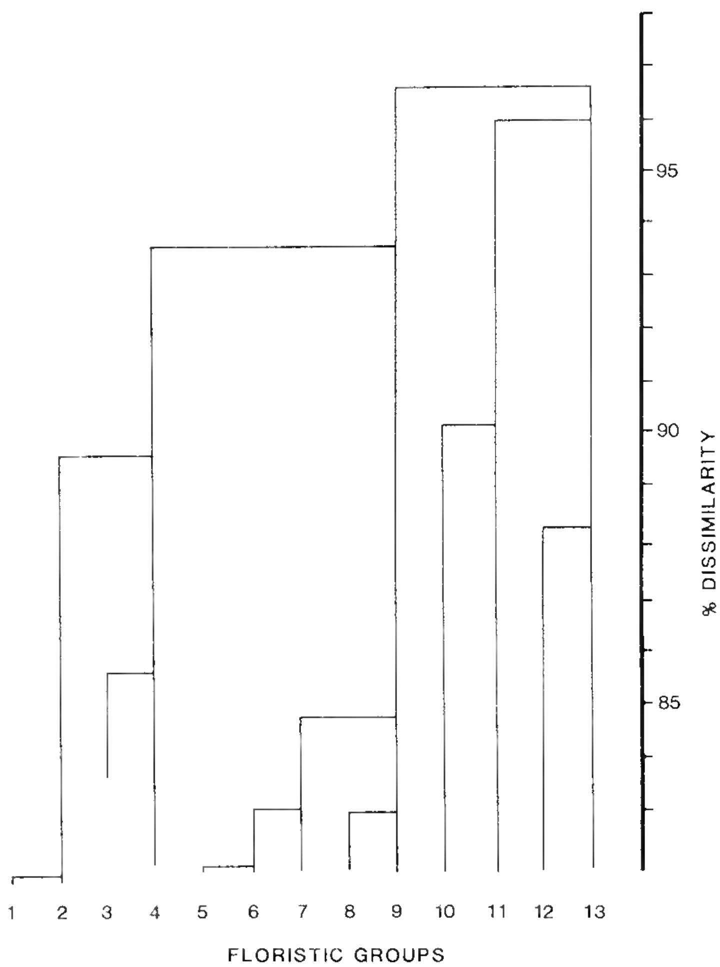

Figure 2 Dendrogram of floristic similarities of quadrats placed at Victoria River. The classification was truncated at the thirteen group level.

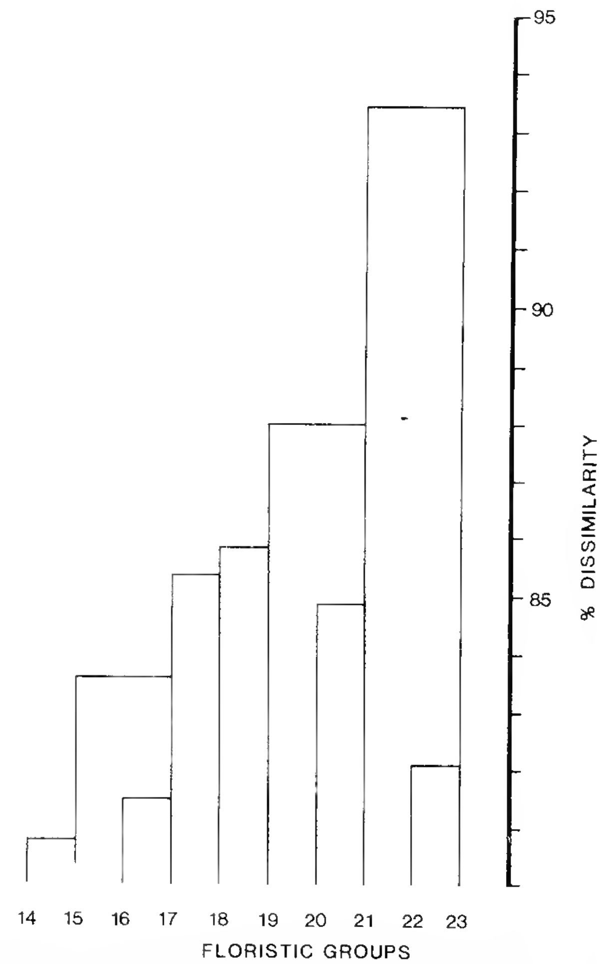

Figure 3 Dendrogram of the floristic similarities of the quadrats placed at Bullita. The classification was truncated at the ten group level.

Table 3

Structural classification (Specht 1981) and dominant species for upper, mid and lower strata of floristic groups at Bullita.

Group No	Upper stratum	Middle stratum	Lower stratum
14	Woodland of *Lysiphyllum cunninghamii E. tectifica, E. terminalis, E. pruinosa* and *Adansonia gregorii*.	Shrubland of *Ampelocissus acetosa* and *Hakea arborescens*.	Grassland of *Heteropogon contortus* and *Sorghum plumosum*.
15	Open-woodland of *Lysiphyllum cunninghamii, E. tectifica, Terminalia canescens*.	Open-shrubland of *Carissa lanceolata Ampelocissus acetosa* and *Flueggea virosa*.	Grassland of *Sorghym plumosum Themeda avenacea* and *Heteropogon contortus*.
16	Low open-woodland of *E. brevifolia, E. dichromophloia* and *Terminalia canescens*	Open-shrubland of *Ampelocissus acetosa, Flueggea virosa* and *Cochlospermum fraseri*.	Grassland of *Plectrachne pungens Themeda avenacea* and *Sehima nervosum*.
17	Low open-woodland of *E. dichromophloia* and *E. ferruginea*.	Open-shrubland of *Grevillea pyramidalis* and *Ampelocissus acetosa*.	Grassland of *Sorghum plumosum* and *Plectrachne pungens*.
18	Tall Shrubland of *Acacia leptocarpus* and *Acacia lysiphloia* with emergent *E. tectifica*		Grassland of *Heteropogon contortus Aristida browniana* and *Sehima nervosum*.
19	Open-woodland of *Adansonia gregorii, E. tectifica* and *E. pruinosa*.	Shrubland of *Dodonaea physocarpa* and *Ampelocissus acetosa*	Grassland of *Plectrachne pungens* and *Aristida browniana*.
20	Open-forest of *Terminalia platyphylla Lophostemon grandiflorus, Melaleuca leucadendra* and *Ficus coronulata*.	Shrubland of *Flueggea virosa* and *Acacia holosericea*.	Grassland of *Heteropogon contortus* and *Echinochloa colona*.
21	Low closed-forest of *Celtis philippinensis, Ficus* spp. and *Strychnos lucida*.		Open herb/vineland of *Passiflora foetida, Jasminum didymum*
22	Open-shrubland of *Acacia laccata* and *Cochlospermum fraseri*.		Grassland of *Plectrachne pungens*
23	Low open-woodland of *E. ferruginea* and *E. brevifolia*.	Open-shrubland of *Grevillea angulata, Grevillea refracta* and *Acacia spp*.	Open-grassland of *Plectrachne pungens* and *Eriachne* spp.

Relationship of mapping units and floristic communities

Tables 4 & 5 show there is a significant relationship between floristic communities and mapping units. However this relationship is not perfect; one floristic group may be significantly associated with more than one mapping unit, as some communities are not possible to differentiate on the maps due to scale and their diffuse boundaries. Two mapping units (10 & 11) are significantly associated with the same florisitic community (Group 14). However mapping unit 11 contains riverine communities (Groups 19 & 20) in contrast to unit 10.

Table 4

Frequency of quadrat occurrence by floristic group and mapping unit at Victoria River. Asterisks denote values showing significant associations following one sample Chi-square analysis (* P<0.05, ** P<0.01, ***P<0.001).

Mapping unit	Floristic group 1	2	3	4	5	6	7	8	9	10	11	12	13
1	1	0	0	0	18***	3*	4*	0	3	2	14***	0	0
2	18**	0	13*	5	8	0	1	2	1	1	0	1	0
3	2	10***	11*	6**	1	0	0	1	0	0	0	2	1
4	2	9***	4	0	0	0	0	2	0	0	0	0	0
5	1	0	0	0	3	2	1	5	6***	0	0	0	0
6	9***	0	0	0	1	0	0	0	0	0	0	0	0
7	0	0	0	0	2	4***	1	0	0	0	0	0	0
Total	33	19	28	11	33	9	7	10	10	3	14	3	1

Table 5

Frequency of quadrat occurrence by floristic group and mapping unit at Bullita. Asterisks denote values showing significant associations following one sample Chi-square analysis (* P<0.05, ** P<0.01, ***P<0.001).

Mapping Unit	Floristic Group 14	15	16	17	18	19	20	21	22	23
8	0	0	0	0	0	0	1	1	0	0
9	5	8	3	0	1	0	0	0	1	0
10	19*	5	0	0	2	0	0	0	1	0
11	41*	2	1	0	1	5*	9*	3	0	0
12	0	0	0	0	0	0	0	0	0	0
13	1	11***	8***	0	1	0	0	1	0	0
14	0	1	5*	2***	0	0	0	0	1	6*
Total	66	27	17	2	5	6	10	6	3	6

Environmental relationships

Tables 6,7,8 & 9 show that the vegetation types defined by the numerical classification are strongly related to topographic position and substrate material. Table 10 shows that substrate material is significantly associated with landform. Therefore the the communities can be primarily grouped by landform with secondary differentiation by substrate material.

Table 6

Frequency of quadrat occurrence by floristic group and topographic position at Victoria River. Asterisks denote values showing significant associations following one sample Chi-square analysis (* P<0.05, ** P<0.01, ***P<0.001).

Topographic position	Floristic group 1	2	3	4	5	6	7	8	9	10	11	12	13
Mesa top	10*	15**	2	0	0	0	0	0	0	0	0	0	0
Mesa rim	1	1	11***	2	1	0	0	2	5	0	0	0	0
Mesa side-slope	11**	0	4	0	5	0	1	4*	0	0	0	0	0
Mesa gully	0	0	8***	7*	0	0	0	0	1	0	0	2**	0
Hill top	4	0	0	0	3	1	0	1	0	0	0	0	0
Hill side-slope	2	1	0	0	0	0	0	1	0	0	0	0	0
Plain	2	0	0	0	9*	8***	4**	0	0	0	1	0	0
Permanent water course	0	1	1	2	10	0	1	2	0	2	13***	1	1
Epemeral water course	2	1	0	0	5	0	0	0	4***	1	0	0	0
Drainage basin	1	0	0	0	0	0	1	0	0	0	0	0	0
Missing			2										
Total	33	19	26	11	33	9	7	10	10	3	14	3	1

Table 7

Frequency of quadrat occurrence by floristic group and substrate type at Victoria River. Asterisks denote values showing significant associations following one sample Chi-square analysis (* P<0.05, ** P<0.01, ***P<0.001).

Substrate Type	Floristic group												
	1	2	3	4	5	6	7	8	9	10	11	12	13
Basalt	2	0	0	0	1	1	0	1	4**	0	0	0	0
Laterite	7***	1	0	0	1	0	0	1	2	0	0	0	0
Sandstone	22	17	28***	11	9	5	3	8	0	1	0	2	0
Alluvium	0	0	0	0	22***	3	4	0	4	2	14***	0	1
Limestone	0	1	0	0	0	0	0	0	0	0	0	0	0
Missing	2											1	
Total	31	19	28	11	33	9	7	10	10	3	14	2	1

Table 8

Frequency of quadrat occurrence by floristic group and topographic position at Bullita. Asterisks denote values significantly associated, following one sample Chi-square analysis (* P<0.05, ** P<0.01, ***P<0.001).

Topographic position	Floristic group									
	14	15	16	17	18	19	20	21	22	23
Mesa top	0	0	2	2**	0	0	0	0	1	6**
Mesa rim	0	0	4*	0	0	0	0	2**	0	0
Mesa side-slope	3	21***	8	0	1	0	0	1	2	0
Mesa gully	1	2	2	0	1	0	1	0	0	0
Hill top	8	2	0	0	1	0	1	1	0	0
Hill side-slope	3	0	0	0	1	0	0	0	0	0
Plain	33***	2	1	0	0	5**	0	0	0	0
Permanent water course	5	0	0	0	0	0	6***	1	0	0
Ephemeral water course	9	0	0	0	0	0	2	0	0	0
Drainage basin	4	0	0	0	1	0	0	0	0	0
Missing						1		1		
Total	66	27	17	2	5	5	10	5	3	6

Table 9

Frequency of quadrat occurrence by floristic group and substrate at Bullita. Asterisks denote values showing significantly associations, following one sample Chi-square analysis (* P<0.05, ** P<0.01, ***P<0.001).

Substrate Type	Floristic group									
	14	15	16	17	18	19	20	21	22	23
Limestone	34	13	1	0	4	0	3	4	2	0
Sandstone	14	11	12	2	1	0	0	1	1	6***
Lime/Sandstone	1	3	3**	0	0	0	0	0	0	0
Alluvium	17	0	1	0	0	5***	7**	0	0	0
Missing						1		1		
Total	66	27	17	2	5	5	10	5	3	6

Table 10

Frequency of quadrat occurence by topographic position and geology for Victoria River and Bullita. Asterisks denote values significantly associated following one sample Chi-square analysis (* P<0.05, ** P<0.01, ***P<0.001).

Topographic position	Substrate Type					
	Laterite	Sandstone	Lime/Sandstone	Limestone	Basalt	Alluvium
Mesa top	6***	30**	0	1	1	0
Mesa rim	3	20	0	3	3*	0
Mesa side-slope	2	41	4*	12	2	0
Mesa gully	0	17	3***	3	1	1
Hill top	1	5	0	2	0	0
Hill side-slope	0	7	0	12***	2	1
Plain	0	18	0	14	0	33***
Permanent-watercourse	0	8	0	5	0	33***
Ephemeral-watercourse	0	6	0	8	0	10
Drainage Basin	0	3	0	2	0	2
Total	12	155	7	62	9	80

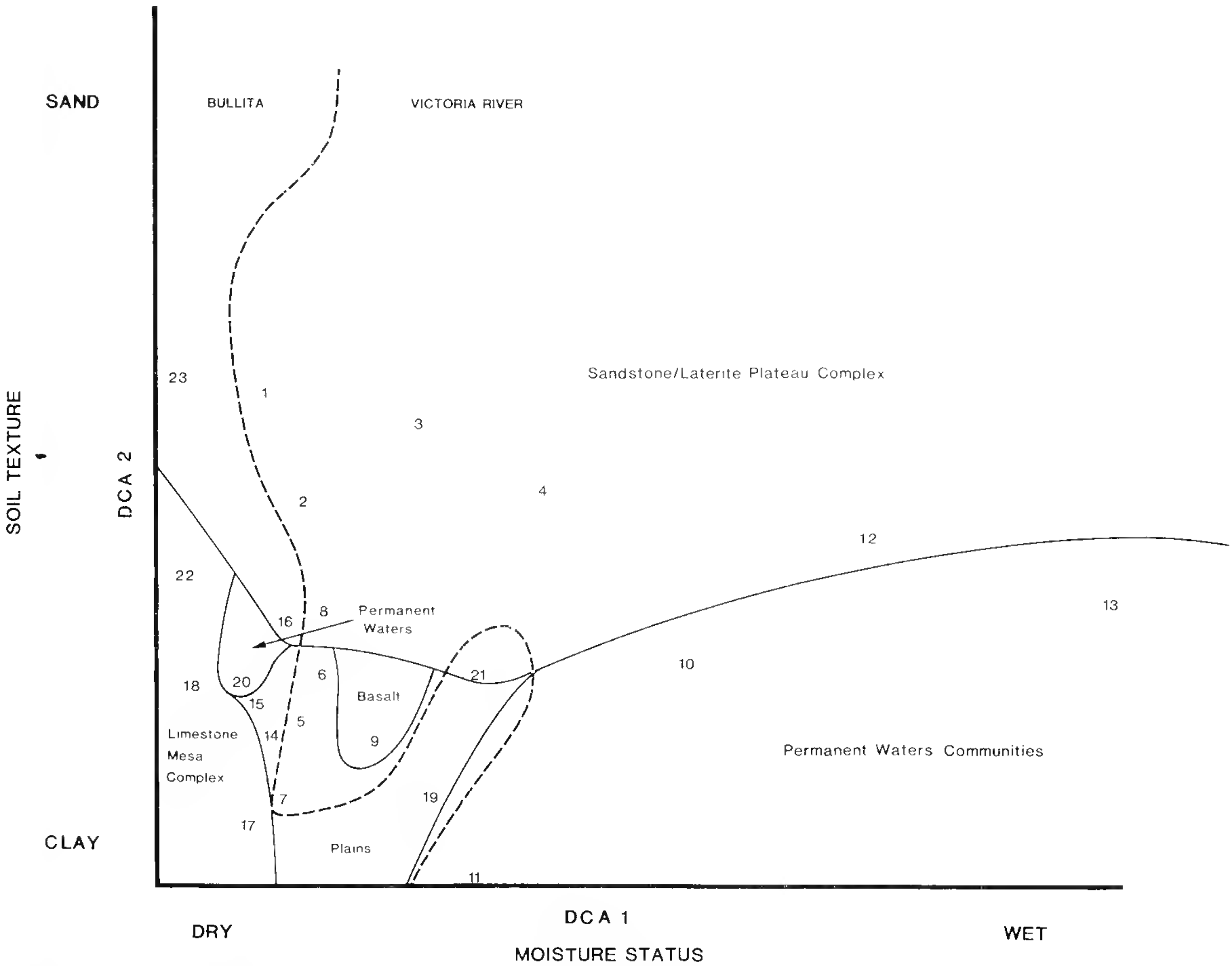

Figure 4 Plot of the centroids of the floristic classifications of the Victoria River and Bullita floristic groups derived from the classification in the first two axes of a Detrended Correspondence Analysis ordination (DCA). The dashed line indicates the division between Victoria River and Bullita. Envelopes are placed around centroids with like geologies and landforms.

Mesa plateau communities

All plateau and mesa tops support eucalypt low open-woodlands. Floristic groups 1 and 2 dominate the sandstone and laterite plateaux at Victoria River. At Bullita Group 17 and 23 occur on sandstone substrate plateaux.

Mesa plateau and mesa/hill rim communities

The sandstone plateau rims at Victoria River are dominated by *Eucalyptus miniata* woodlands of floristic Group 3. At Bullita limestone and/or sandstone rims support *E. brevifolia* low woodlands (Group 16) while limestone rims carry low *Celtis philippinensis* closed-forest (Group 21).

Mesa sideslopes

Mesa sideslopes at Victoria River support *E. dichromophloia* woodlands (Group 1). These sandstone slopes support low woodlands dominated by *Erythrophleum chlorostachys* (Group 8). At Bullita sandstone slopes support *Lysiphyllum cunninghamii* dominated woodlands (Group 15) while limestone slopes are either covered in this community or open-shrublands dominated by *Acacia laccata* (Group 22).

Mesa gullies

Three communities occur in sandstone gullies at Victoria River. *Eucalyptus miniata* woodlands (Group 3), which also occur on plateau rims, occur in the driest gullies. In moist gullies *Livistonia* 'Victoria River' forests occur (Group 4). In deep protected gullies closed-forests dominated by *Syzygium angophoroides* shade fern understories (Group 12). The gullies on mesas at Bullita are shallow and do not support characteristic vegetation types.

Hills

Hill communities are only significant at Bullita, associated with rounded limestone outcrops. They support tall shrubland dominated by *Acacia leptocarpa* (Group 18).

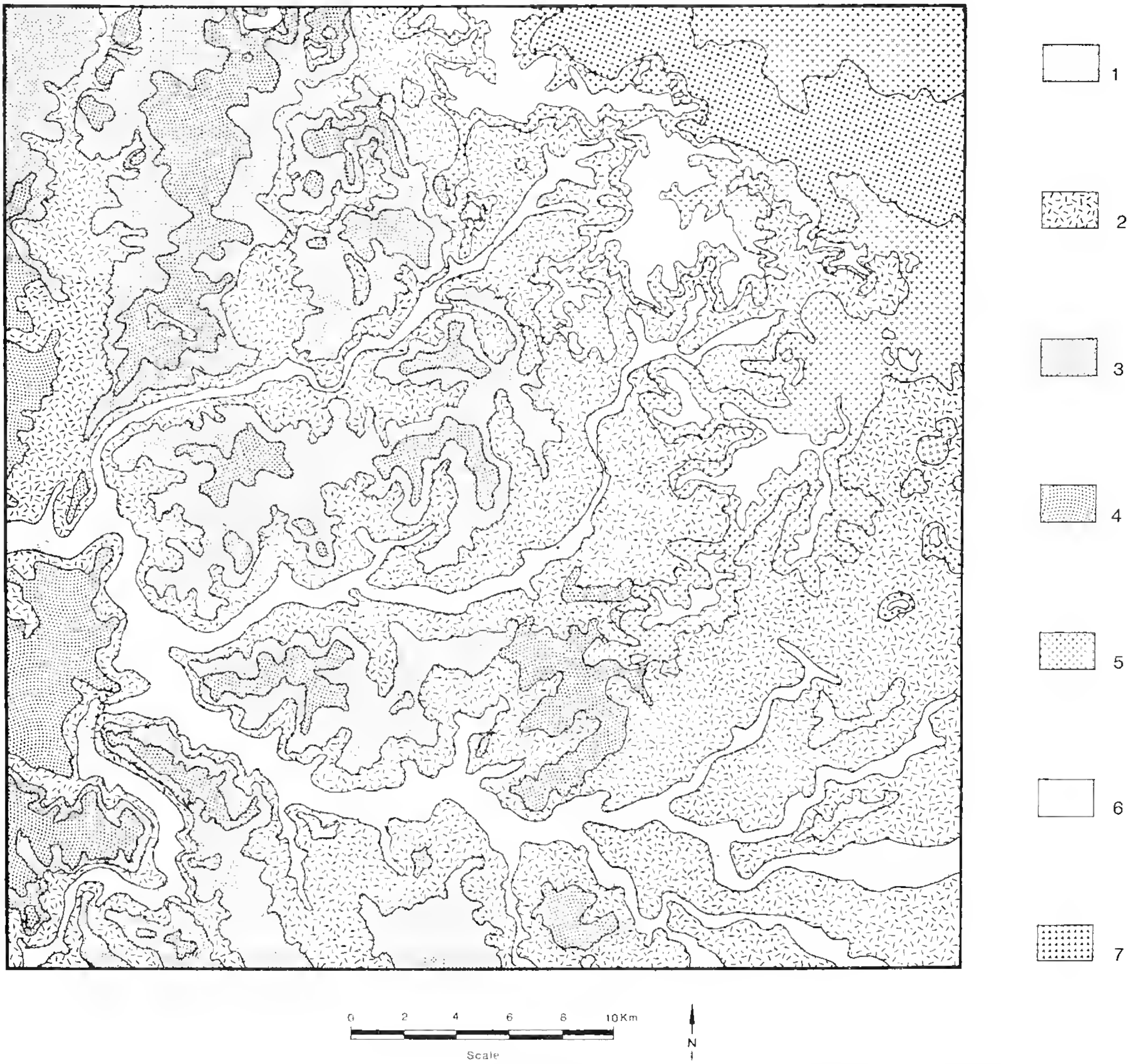

Figure 5 Map of repeatable photo-patterns at Victoria River. Mapping units correspond to the following environments: **1** Plains and Rivers; **2** Sandstone plateau sideslopes; **3** Sandstone plateau rims and upper slopes; **4** Sandstone plateau tops; **5** Basalt sideslopes; **6** Lateritised basalt plateaux; **7** Basalt plains.

Plains

Alluvial plains with residual rock outcrops support three interrelated types of *E. tectifica* woodlands (Groups 5, 6 & 7). At Bullita the alluvial deposits on the plains support *E. tectifica* open-woodlands with emergent *Adansonia gregorii* trees (Group 19). *Lysiphyllum cunninghamii* woodlands are found on sites with either limestone or sandstone rock, or alluvial deposits (Group 14).

Permanent water communities

These communities are more diverse and abundant at Victoria River than Bullita. In the Victoria River area, *E. camaldulensis* woodlands are found on levees with deep alluvial soils (Group 11). Low *Melaleuca argentea* woodlands (Group 10) occur on river banks. In poorly drained depressions low *Melaleuca symphyocarpa* closed-forest occur (Group 13). At Bullita *Lophostemon grandiflora* open-forest characterizes the riverine communities (Group 20).

Ephemeral water communities

The dry creeks on basalt plateaux support mixed species open-'monsoon' forest dominated by species such as *Ziziphus quadrilocularus* and *Strychnos lucida* (Group 9).

Species diversity of the landform-vegetation complexes

The ephemeral water community is the most species rich community (26.9 species per 100 m^2) while the permanent water communities have the greatest range of species richness (7—19.9 species per 100 m^2). The plains communities are generally richer than the elevated communities with the exception of the low *Erythrophleum* woodland (Group 8) which is the second most diverse community (Appendix).

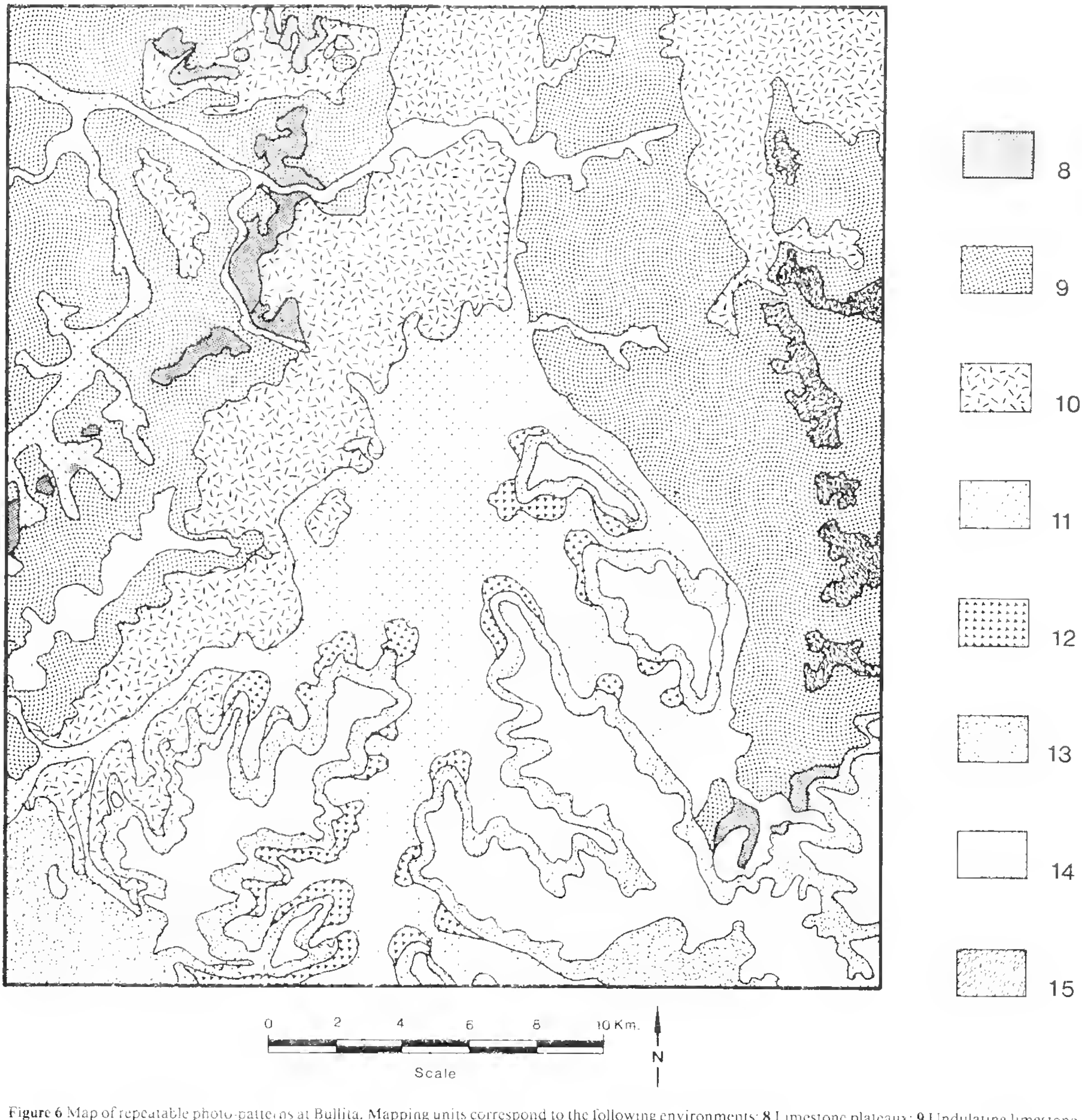

Figure 6 Map of repeatable photo-patterns at Bullita. Mapping units correspond to the following environments: **8** Limestone plateaux; **9** Undulating limestone country; **10** Plains and rivers; **11** Plains; **12** Eroded devegetated areas; **13** Sandstone/Limestone mesa sideslopes, **14** Sandstone/Limestone mesa tops, Not ground truthed.

Comparison between Victoria River and Bullita areas

Ordination of the centroids of the 23 communities shows that the main differences between Bullita and Victoria River is moisture status and the occurence of basalt and limestone (Figures 4, 5 & 6). The permanent water community at Bullita is floristically distinct from the four at Victoria River, the former sharing more species with the limestone hill complex. The limestone mesa complex is distinct from the sandstone and laterite plateau complex possibly due to the formers clay-rich basic soils which gives it more affinity with the plains communities. The plain communities are similar at both Bullita and Victoria River even though the geologies of the two areas are different. The sandstone/laterite plateau complex is shared by both Bullita and Victoria River. The driest communities in this complex occur at Bullita while at Victoria River these communities span the moisture gradient (as defined by DCA 1) from plateaux with skeletal soils through to deep sheltered canyons. Variation in the plateaux communities at Bullita is associated with changes in surface soil texture and substrate material (DCA 2).

Comparison of Gregory with other areas in northern Australia

The vegetation communities described at Victoria River and Bullita approximate the general descriptions provided for the Ord-Victoria area by Perry (1970), the Bungle Bungle Ranges by Forbes & Kenneally (1986) and Keep River National Park by Henshall & Mitchell (1979) and Sivertsen & Van-Cuylenburg (1986). More detailed floristic comparisons with the complete Gregory list (Appendix) were made with the above authors' species lists, the list for Uluru National Park (or Ayers Rock, Hooper *et al.* 1973), Katherine Gorge N P (Sivertsen & Day 1986), Alligator Rivers Region (or Kakadu, Taylor & Dunlop 1985) and Litchfield Park (or Tabletop Range, Kirkpatrick *et al* 1988 and Lynch & Manning 1988) (Fig. 7 and Table 11). Because the above surveys were conducted in different seasons and at different levels of intensity, a conservative measure of floristic similarity was used: number of species in common / the lowest number of species in either species list. This analysis shows that Keep River has the highest similarity with Gregory (53%) while Ayers Rock has the least number of species in common (10%). Katherine Gorge, the Bungle Bungles, Alligator Rivers and Litchfield have lower similarities (42, 37, 33 & 34% respectively).

The similarities of the areas generally reflect north-south changes in rainfall. The Bungle Bungles, however, are situated further south and inland than Gregory (Fig. 3) but have a comparable rainfall (Forbes & Kenneally 1986). The relatively low similarity of this area with Gregory appears to be largely due to the number of rainforest species (eg *Ficus virens* and *Euodia elleryana*) that are found in the deep gullies at the Bungle Bungles that are not found at Gregory. Such refugia appear to be smaller and less common at Victoria River and rare at Bullita. These results concur with the findings of Kirkpatrick *et al* (1988) that sandstone communities are more spatially variable than the more uniformly distributed savanna communities in the northern coastal regions of the Northern Territory.

Table 11

Floristic similarity of various areas in the Northern Territory to Gregory National Park

Location	Uluru N P (Ayers Rock)	Keep River N P	Bungle Bungle Range	Katherine Gorge N P	Litchfield Park (Tabletop Range)	Alligator Region (Kakadu)
Total Species Recorded	320	301	657	165	423	657
Number of Species in common with Gregory	32	160	152	69	144	171
Similarity to Gregory (%)	10	53	37	42	34	33

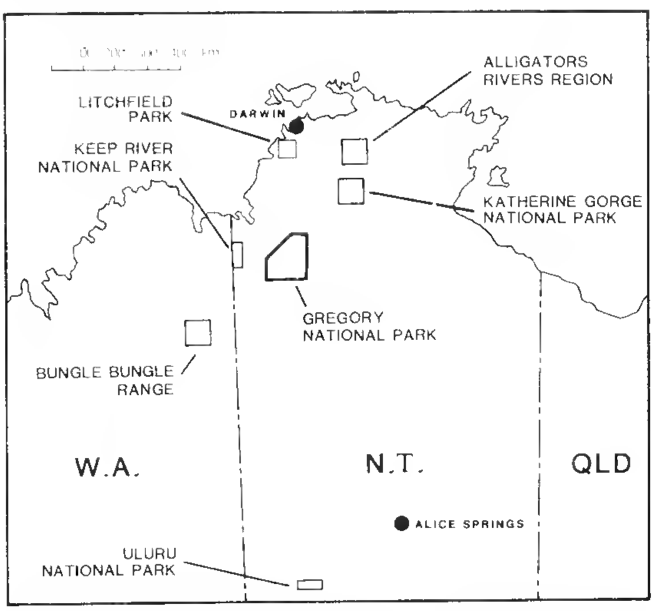

Figure 7 Location of areas from which floristic lists were compared with Gregory National Park.

East-west differences are reflected in a comparison of the number of species held in common with the Alligator Rivers Region between Victoria and Bullita (130 vs 92). The sandstone escarpments and associated canyons are larger and more frequent at Victoria River and carry many species in common with Kakadu (eg. *Eucalyptus miniata, Erythrophleum chlorostachys* and *Ficus* spp.) which do not occur in the drier Bullita environment (Appendix). Further east-west gradients are expressed in the common occurence of *Adansonia gregorii* at Keep River and Bullita but not Victoria River. Also the presence of *Livistona* 'Victoria River' at Victoria River and the Bungle Bungles may reflect an association of sandstone geologies or a relict distribution of the species.

Perry (1970), Forbes & Kenneally (1986), and Sivertsen & Van-Cuylenburg (1986) assume that there is a strong relationship between landform, soils and vegetation. This study has supported this assumption. Perry (1970) notes that after climate, species distributions are most strongly controlled by some factor(s) associated with lithology, particular acidic and basic rocks. This study suggests that local microclimate as determined by landform is very important in controlling vegetation distribution with surface soil texture being a secondary interrelated factor.

Implications for park management

No obviously fire damaged vegetation was encountered in the course of this survey. Burnt sandstone plateau vegetation was observed to be floristically richer than adjacent unburnt patches. The major management problems appear to be associated with introduced herbivores. The bare areas at Bullita (Mapping Unit 12), apparent in the 1968 aerial photography, were still clearly visible at the time of the survey. They may have developed in response to high densities of cattle associated with stock yards and animal camps. Feral donkeys will continue to have an impact on soil erosion following the exclusion of cattle from the park. Clearly there is need to assess the impact and control of these animals.

The second major management problem is associated with the spread of exotic plants throughout the park. The 17 exotic plants encountered in this survey were mainly found on the plain and riverine communities which are also the focus of herbivory. It is likely that a reduction of feral animal populations and subsequent control of erosion will help in controlling the spread of exotics.

Given the variability in plant communities found across the northern part of the Northern Territory, particularly with respect to sandstone areas, there is a need to reserve areas across major environmental gradients to ensure adequate reservation of plant species and habitats. The Gregory National Park is an important addition to the Northern Territory National Park estate as it encompasses previously unreserved plains communites and an important area of sandstone vegetation in an arid extreme of the Australian monsoon tropics.

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Consanguineous wetlands and their distribution in the Darling System, Southwestern Australia

C A Semeniuk

21 Glenmere Road Warwick WA 6024

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Abstract

In the Darling System of Southwestern Australia, similarity in physical setting and causative factors of wetland development produces suites of wetlands with common or inter-related features. These genetically related wetlands are termed consanguineous and form assemblages termed consanguineous suites. Consanguineous suites are identified on criteria of wetland type, wetland geometry, stratigraphy, inferred origin, and water characteristics. In total some 42 consanguineous wetland suites are recognized throughout the Darling System. Consanguineous closely occurring wetlands can be grouped into discrete areas referred to herein as domains. These domains occur throughout the Darling System either in recurring patterns (eg such as the basin wetlands within the Bassendean Dune system) or in unique localities (eg such as Benger Swamp or Lake Pinjar). Domains can most readily be related to the large scale geomorphic units. Wetlands within each geomorphic system exhibit characteristic and distinguishing shapes. Wetlands of the Bassendean Dunes are usually round or irregular, isolated to coalesced, basins. Wetlands within the Spearwood Dunes are irregular to elongate or linear basins occurring in linear chains. Most wetlands within the Quindalup Dunes are very small basins in comparison to those in other geomorphic systems. Wetlands of the Pinjarra Plain and Darling Plateau are channels and associated flats.

Introduction

The Darling System, comprising the Swan Coastal Plain, Dandaragan Plateau and Darling Plateau, of southwestern Australia (Fig. 1) contains a wide range of wetland types, which vary in size, shape, water characteristics, stratigraphy and vegetation. These attributes are determined by regional features such as geology, geomorphology, soils, climate and hydrology and local physical/chemical processes such as fluvial processes, aeolian processes, groundwater flow and karstification. Each wetland is the culmination of these ancestral and modern processes, inherent developmental stratigraphy, and vegetation influences. When the factors of geomorphic setting, origin and water maintenance are common to a group of wetlands, a marked similarity is evident and wetland types can be seen to be related or consanguineous. The wetlands of the Darling System can be compartmentalized into localities, or domains of occurrence, that reflect the distribution of these related wetlands.

To date, while there have been studies of individual wetlands and wetland systems in the study area (eg Riggert 1966, McComb & McComb 1967, Passmore 1970, Tingay & Tingay 1976, Congdon & McComb 1976, Wetlands Advisory Committee 1977, Watson & Bell 1981), few studies have placed wetlands into a regional perspective in terms of their categories and the distribution of these categories. Serventy *et al.* (1971), Arnold & Sanders (1981) and Allen (1981) are an exception to this in that they attempted to categorize wetlands according to origin (Serventy *et al.* 1971), or into lake types (Allen 1981), or attempted to locate categories of wetlands geographically in the Perth metropolitan region (Arnold & Sanders 1981). However, their studies did not encompass the full variety of wetlands in the Darling system, and did not extend beyond the Perth region. This paper attempts to provide information on the numerous and varied categories of wetlands throughout the region of the Darling System (ie identifying related types or, in the terminology of this paper, consanguineous suites), and also attempts to show their distribution in discrete occurrences (or domains).

The objectives of this paper therefore are to: 1 define the criteria for recognising consanguineous wetlands, 2 identify and describe consanguineous wetlands, and 3 delineate domains which contain consanguineous wetland suites within the Darling System between Moore River and Collie River (Fig. 1).

Regional Setting

There are a range of regional physical features which are important to understanding the development of wetland types and their distribution in the Darling System. The physical features are: geology, geomorphology, soils and geomorphic processes, climate; and hydrology. These features can directly control the development of wetlands, and their variation either regionally or locally can produce variability of wetland types.

Geology, Geomorphology, Soils and Geomorphic Processes

The geology and soils of the Darling System have been described by Northcote *et al* (1967), McArthur & Bettenay (1960), Playford *et al* (1976), Wilde & Low (1978, 1980), Biggs *et al.* (1980), and Wilde & Walker (1982). The Darling System comprises two distinct geological provinces separated by the Darling Fault. East of the fault are Precambrian crystalline rocks of the Yilgarn Block, with local outliers of Phanerozoic sediments (eg Collie Basin) and a variable regolith cover. To the west of

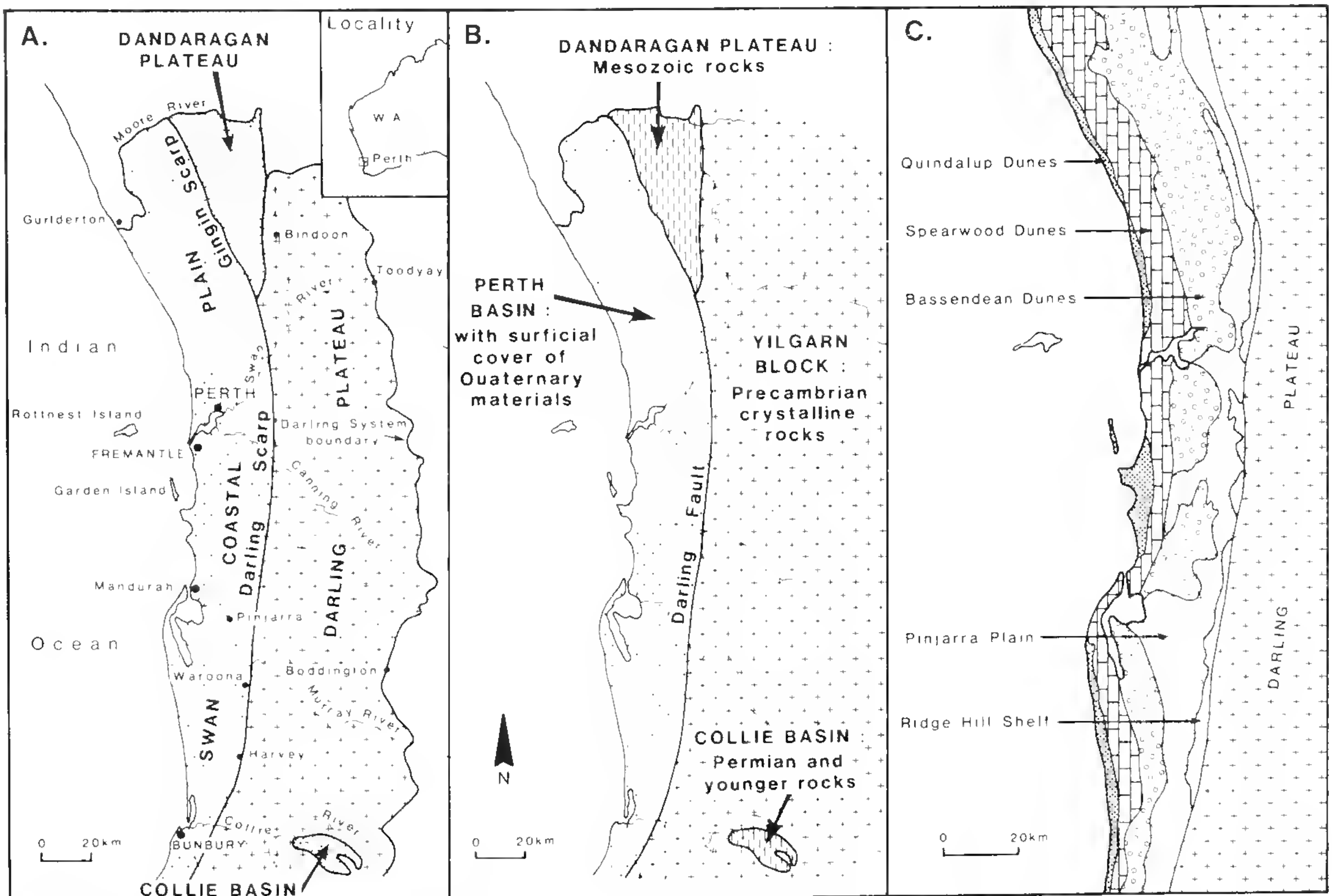


Figure 1 Regional setting. *A* Geomorphic units. *B* Geology. *C* Geomorphic elements of the central part of the Swan Coastal Plain after McArthur & Bettenay (1960).

the fault is the Perth Basin, a deep trough filled with Phanerozoic sedimentary rocks, extant up to the Quaternary. For this paper two regions of the Perth Basin are distinguished (Biggs *et al.* 1980): **1** Quaternary surficial deposits, and 2 Mesozoic rocks.

Regional geology has a major influence on the pattern of landforms of the Darling System and consequently Churchward & McArthur (1980) used a geological framework as the basis of primary classification of landform-soil units. These units, which occur within the study area, are (Fig. 1): the Darling Plateau of Precambrian crystalline rocks and regolith; the Collie Basin of Permian and younger sediments; the Dandaragan Plateau of Mesozoic rocks and regolith; and the Swan Coastal Plain of Quaternary surficial deposits.

Each of these units has a distinctive suite of large, medium and small scale landforms and soils as a result of geomorphic and pedologic processes. In addition, because of their setting and distinctive stratigraphy, the units may influence development of varying types of small scale hydrologic patterns. These geomorphic and hydrologic features have a bearing on determining the type and distribution of wetlands within the various geomorphic settings of the Darling System. Since most wetland types are determined by the large and medium scale geomorphic structure of an area a brief description of the geomorphology at these scales is presented below.

The Darling Plateau is a broadly undulating surface with laterite overlying Precambrian crystalline rocks. It is separated from the Swan Coastal Plain by the Darling Scarp. The Plateau reaches an average height of 400m above sea level, and is dissected by steep sided valleys with incised channels and by steep sided valleys with broad, flat, ribbon shaped floodplains and small channels. Both the general character of the rock types and the structural trends influence to a marked extent the nature and disposition of wetland types on the terrain of the Plateau. Fluvial geomorphic processes are dominant and consequently channel and flat (floodplain) wetland categories predominate.

The Collie Basin forms a large topographic depression within the Darling Plateau. It is underlain by laterite-capped Permian and younger rocks. Landscapes have very low relief ranging from 200m to 250m above sealevel. As a result, although fluvial processes are dominant, channels tend to be broad, shallow and flat-floored, with wide accompanying ribbon floodplains.

Mesozoic rocks underlie the Dandaragan Plateau which extends in a splinter block north from Perth, bound to the east by the Darling Fault and to the west by the Gingin Scarp. The Dandaragan Plateau also is a laterite capped surface, but is less dissected than the Darling Plateau, and its surface, some 200m above sealevel, is gently undulating. Again the character of the rocks and their weathering/erosion patterns has a major influence on the development of wetland types. Fluvial processes predominate but because of the relatively low internal relief, rivers and creeks are not deeply incised and tend to be broad-based with wide floodplains, gently grading upward into valley slopes.

The Swan Coastal Plain in its entirety extends from Dongara to Busselton (Gentilli & Fairbridge 1951) but only the southern-central portion is relevant here. The plain generally is of low relief and is some 20-30km wide. The Quaternary surficial deposits, of Pleistocene to Holocene age and sedimentary and pedogenic origin, blanket most of the plain (Playford *et al.* 1976), and the major formations therein correspond to the location of the geomorphic elements of McArthur & Bettenay (1960) and McArthur & Bartle (1980a,b). There is a marked zonation of distinct large scale landforms either arranged parallel to the coast or associated with major rivers. Within each zone there is an array of distinctive medium and small scale landforms, geomorphic processes and hydrologic patterns that are important to the development of distinct suites of wetlands. The zones, as documented by Woolnough (1920), McArthur & Bettenay (1960) and McArthur & Bartle (1980a,b), together with their stratigraphic units, from east to west are (Fig. 1):

- The Ridge Hill Shelf, underlain by laterite, clay and sand of the Yoganup Formation (Low 1971), occurring along the foothills of the Darling scarp. It is dissected by many microscale channels and contains occasional lakes and sumplands.

- The Pinjarra Plain, a flat to gently undulating system of alluvial fans, floodplains and various sized channels; the underlying sediments are the Guildford Formation (Low 1971). The medium and small scale geomorphology is dominated by channels, flats and plains.

- The Bassendean Dunes, an undulating plain of low degraded quartz sand hills and associated hollows varying in relief from 20m to almost flat; the sands are Pleistocene and are termed Bassendean Sand (Playford & Low 1972). The medium and small scale geomorphology is alternating hills and basins, and drainage channels generally are absent.

- The Spearwood Dunes and Yoongarillup Plain (McArthur & Bartle 1980b), comprising large-scale, linear, continuous parallel ridges (*c* 20m relief) and intervening narrow and steep-sided depressions. The underlying materials are predominantly Pleistocene aeolianites (Tamala Limestone) blanketed by yellow quartz sand, and, to the south underlying the Yoongarillup Plain, yellow quartz sand, Pleistocene aeolianites and marine limestone. Large scale to medium scale landforms are depressions and gently undulating hills. Drainage channels are absent and the processes of sheet wash, basin sedimentation, karstification and subterranean solution are important geomorphic processes in the development of wetlands.

- The Quindalup Dunes encompass Holocene dune ridges, beach ridge plains, tombolos and cuspate forelands along the modern coast; the underlying sediments are Safety Bay Sand. Medium and small scale landforms include parabolic dunes (20m high) with associated deflated areas, linear low ridges (3-6m high) and associated depressions, and isolated hills and hollows. Locally there are large lakes originally formed by marine influences.

Semeniuk (1983) described additional surficial formations in the Bunbury area: the Leschenault Formation composed of estuarine sediments, and the Eaton Sand that comprises sand ridges co-linear with the Spearwood Dunes.

In addition to the above units the contacts between the various geomorphic units constitute important settings for the development of distinct wetland zones or the development of transition zones. For instance, the junction between Spearwood Dunes and Quindalup Dunes, and the junction between Spearwood Dunes and Bassendean Dunes contain distinct chains of wetlands (McArthur & Bettenay 1960; Allen 1980). So too the contact of Pinjarra Plain (alluvial fans) and Bassendean Dunes, and the Darling Scarp itself can develop distinct chains of wetlands.

Climate

The climate of the Darling System is typically Mediterranean (Gentilli 1972) with north-south and east-west gradients in precipitation, evaporation, temperature and wind. The north of the Darling System is semiarid to subhumid, the central part is subhumid to humid, and the south is humid (Gentilli 1972).

Rainfall exceeds 1000mm/yr in southern areas, and along the margin of the Darling Plateau/Darling Scarp. It decreases to *c* 600mm/yr both in northern areas and eastwards toward the wheatbelt (Gentilli 1972; Bureau of Meteorology 1975). Rainfall is markedly seasonal occurring mostly during May to October (Bureau of Meteorology 1973). In response, wetlands of the Darling System exhibit a seasonal variation in water depth, flow and water quality. The period of lowest rainfall coincides with the period of maximum evaporation. Evaporation ranges from 2000mm/yr in the north of the Darling System to *c* 1200mm/yr in the south. Temperature variations also occur throughout the Darling System, increasing slightly to the north and east.

Wind is important in development of sediments, wetland margins, and some wetland types. Wind generates waves on standing water of lakes, sumplands and estuaries, and these waves effect sediment winnowing, transport and the development of peripheral beachridges. Wind in the coastal zone is important in developing marine and coastal landforms and their accompanying distinctive wetlands. For instance, dune blowouts developed by wind can form into wetlands; swales in beachridge plains may also develop distinctive wetlands; and, at the large scale, coastal landforms such as barrier dunes (Semeniuk 1985) develop and protect large scale wetlands and estuaries.

Winds of the Darling System are controlled by eastward migrating anticyclonic pressure cells (Gentilli 1972) and landbreeze - seabreeze systems. Inland areas experience winds from the southeast, east and northeast in summer and, during the winter when water levels of wetlands are elevated, they receive light and variable wind mainly from the eastern and western sectors, with storms from west and northwest. Coastal areas have relatively calm winds during winter, interrupted by storms emanating mainly from northwest and west; during summer the landbreeze - seabreeze system controls the wind, with landbreezes emanating from southeast, east and northeast and seabreezes emanating from southwest and south (Searle & Semeniuk 1985).

Hydrology

The aspects of hydrology important to understanding the development and maintenance of wetlands are recharge mechanisms, storage systems, discharge mechanisms, longevity of water retention and water quality. These differ between wetlands located in the various geomorphic settings, and even between wetlands within the same geomorphic setting, and this can influence the development of different types of wetlands and their biological response. For instance, variability of rainfall can effect volume of surface water, its quality, and type of discharge.

Recharge of water into wetlands may be the result of direct precipitation, water table rise, groundwater discharge from adjoining areas, or surface runoff, all of which are seasonally variable. The type of recharge into a wetland may be dependent not only on the general hydrological setting but also on the local geomorphic setting and the wetland stratigraphy. Basins with clay floors, for example, can pond meteoric water or telluric water discharged from adjoining groundwater mounds, whereas basins with sandy floors in the same geomorphic and hydrologic setting may develop into different types of wetlands. A single hydrological process can produce a range of different wetland types, or can produce a spectrum of interrelated wetland types, because of the variability of landform, stratigraphy and substrates upon which the hydrologic process interacts, eg groundwater seepage results in development of basins in one area and in the development of creeks in another.

Discharge mechanisms may include vegetation-induced evapo-transpiration, direct evaporation, run off, overflow discharge or gravitational percolation/infiltration. The relative importance of each of these is related to climatic setting, type of vegetation, geomorphic setting and stratigraphy. A summary of potential recharge and discharge patterns of wetlands is presented in Fig. 2.

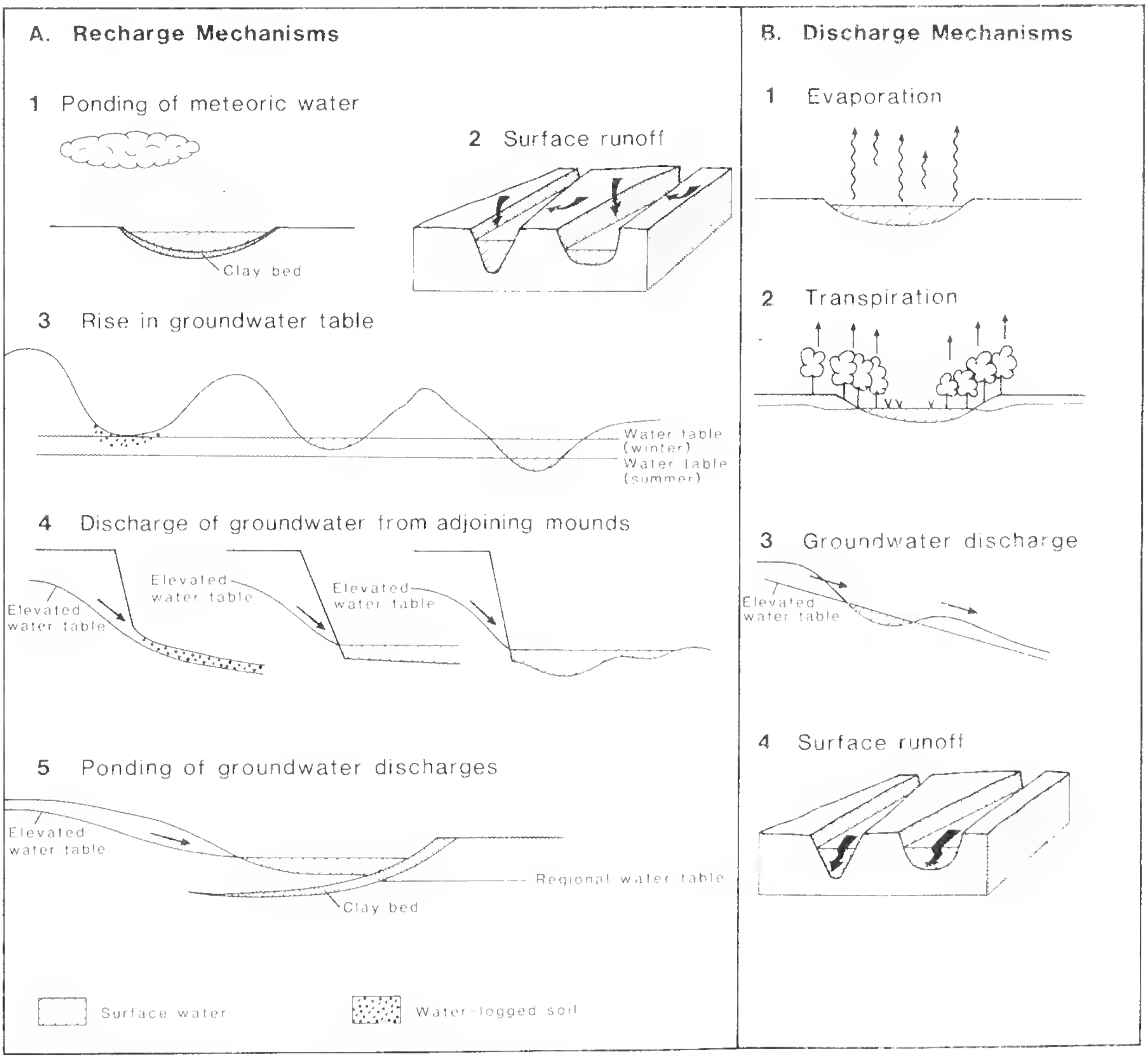


Figure 2 Idealized diagram illustrating a range of recharge and discharge mechanisms that maintain wetlands.

The most obvious hydrological pattern of the Darling System is the seasonality of dynamics and variability of water salinity, due to seasonal rainfall. Volume of surface water in wetlands increases rapidly with the onset of winter rainfall and is maintained by a rise in groundwater levels through to October-November. Thereafter the amount of surface water is reduced by drainage and evaporation, which draws upon groundwater from lower levels and concentrates salts in reduced volumes of water, causing salinity to increase (Allen 1976, 1981).

Biggs *et al.* (1980) summarized the hydrogeology of the Darling System, and Allen (1976, 1981) described much of the relevant hydrology of the Swan Coastal Plain as it relates to wetlands. These authors identified the major groundwater storage systems in the region. Biggs *et al.* (1980) recognized within the Darling System a number of groundwater zones: a Darling Plateau zone, a Collie Basin zone, and a variable range of zones within the Swan Coastal Plain. The hydrological functions within an area that determine recharge, maintenance, or discharge of water from wetlands can be broadly related to large scale geomorphic setting and local stratigraphy and their relationship to the regional hydrologic pattern.

In the Darling Plateau, for instance, steep surface gradients and impermeable surface materials result in rapid runoff and channelling, with development of short-lived creek systems or wetland valleys sustained by seepage and/or base flow. On the Dandaragan Plateau, flatter slopes and lower runoff rates result in an extended period of water storage or accumulation in wetland valleys. On the Swan Coastal Plain there is a predominance of basins and consequently fluvial discharge is not important except on the Pinjarra Plain. Meteoric input, discharge from groundwater mounds, or water table rise are the main mechanisms of providing water into these basin wetlands. Surface run off, meteoric input and groundwater discharge (seepage) contribute to channel wetlands on the Pinjarra Plain. Allen (1976, 1981) noted, for instance, that many wetland basins of the Swan Coastal Plain are in hydraulic connection with the water table, but also noted that rainwater can be ponded in the wetlands within the Bassendean Dunes. The results of Allen (1976, 1981) can be extended to the basin wetlands of the Quindalup Dunes and the Pinjarra Plain where they are underlain by hardpans of laterite, iron-cemented sand, clay and calcareous mud.

Allen (1976, 1981) recognized some wetlands as discharge basins for localized springs and broad areas of seepage. These emissions and flow lines occur where steep groundwater gradients exist, or where a juxtaposition of two facies with different transmissivity occurs (*eg* Six Mile Swamp, Nine Mile Swamp, Lake Pinjar, Bibra chain). The hydrologic functions and behaviour along junctions of the various geomorphic units thus can result in distinct wetland belts or chains. These junctions, such as those between all the main geomorphic elements of McArthur & Bettenay (1960), may be zones either of discharge (*eg* contact between Pinjarra Plain and Bassendean Quindalup Dunes) or ponding (*e.g.* between Spearwood Dunes and Bassendean Dunes).

Analytical Methods and Terminology

Fieldwork data base

The results of this paper are based on fieldwork and interpretation of aerial photographs. Fieldwork included reconnaissance surveys of numerous wetlands throughout the region (Fig. 3). Some 20 east-west transects, numerous road traverses and over 300 sites were included in the field documentation of geomorphology, stratigraphy and water quality, 80 of which were monitored seasonally for 3 years (Fig. 3). At these sites geomorphology, stratigraphic history and water maintenance were studied in detail by topographical surveying, shallow augering and trenching (up to 3.5m), drilling (up to 30m), seasonal water sampling, seasonal water depth measurements and surface flow observations.

The information from fieldwork was supplemented by desk studies of aerial photographs, and aerial photograph mosaics at scales of 1:60 000, 1:20 000 and topographic maps at scales of 1:100 000, and 1:5 000, covering the entire Darling System. Each domain identified in this study was examined and described in the field. Additional information on water quality and water depth of numerous wetlands was obtained from the literature (Riggert 1966, Tingay & Tingay 1976, Wetlands Advisory Committee 1977, McComb & McComb 1967, Congdon & McComb 1976, Moore *et al.* 1984, Passmore 1970, Allen 1976, 1980, 1981, Hall 1985).

Classification

To identify consanguineous wetlands it is necessary to apply a standard classification scheme and the classification of C. A. Semeniuk (1987) is adopted here. This classification utilizes the two primary components of wetlands, the "landform" and "wetness" components (Table 1).

Using subdivisions of cross-sectional wetland geometry there are recognized: *basins*, *channels*, and *flats*. The maps of wetland suites in this paper differentiate wetlands only to this level. Combining wetness and landform attributes results in 7 categories of common wetlands: **1** permanently inundated basin = *lake*; **2** seasonally inundated basin = *sumpland*; **3** seasonally waterlogged basin = dampland; **4** permanently inundated channel = *river*; **5** seasonally inundated channel = *creek*; **6** seasonally inundated flat = *floodplain*; and **7** seasonally waterlogged flat = *palusplain*. The detailed information in Table 2 of this paper differentiates wetlands to the level of one of these categories. Water and landform descriptors (Table 1) are used to further augment the nomenclature of the primary categories and discriminate individual wetlands.

The classification as used in this paper is applied to varying degrees of detail. All wetlands can be readily classified as to basin, channel or flat, but the extent of water permanence is not known in some cases so that classification into one of the 7 primary categories was not always possible. In addition, water salinity and its seasonal variability were not known for every wetland produced in the maps of this paper. Lake Joondalup, for instance, could be classified using the full nomenclature with the full range of descriptors. White Lake, Beermullah Lake and Bidaminna Lake could be classified as lakes with a partial listing of descriptors, because in these cases the consistency of water quality is not known. On the other hand some of the wetland basins in the Bunbury-Binningup area could not be classified further than "basin" and the descriptors of size and shape only could be applied. The scale terms applied to geomorphic units in this paper follow Semeniuk (1986). Salinity terms are after Hammer (1986).

The term estuary is used as defined by Day (1981). The environment of the estuary encompasses limnetic and littoral landforms that, in southwestern Australia, include bays, headlands, reaches, shoals, shelves, spits, tidal flats, deltas, tidal deltas and exchange channels.

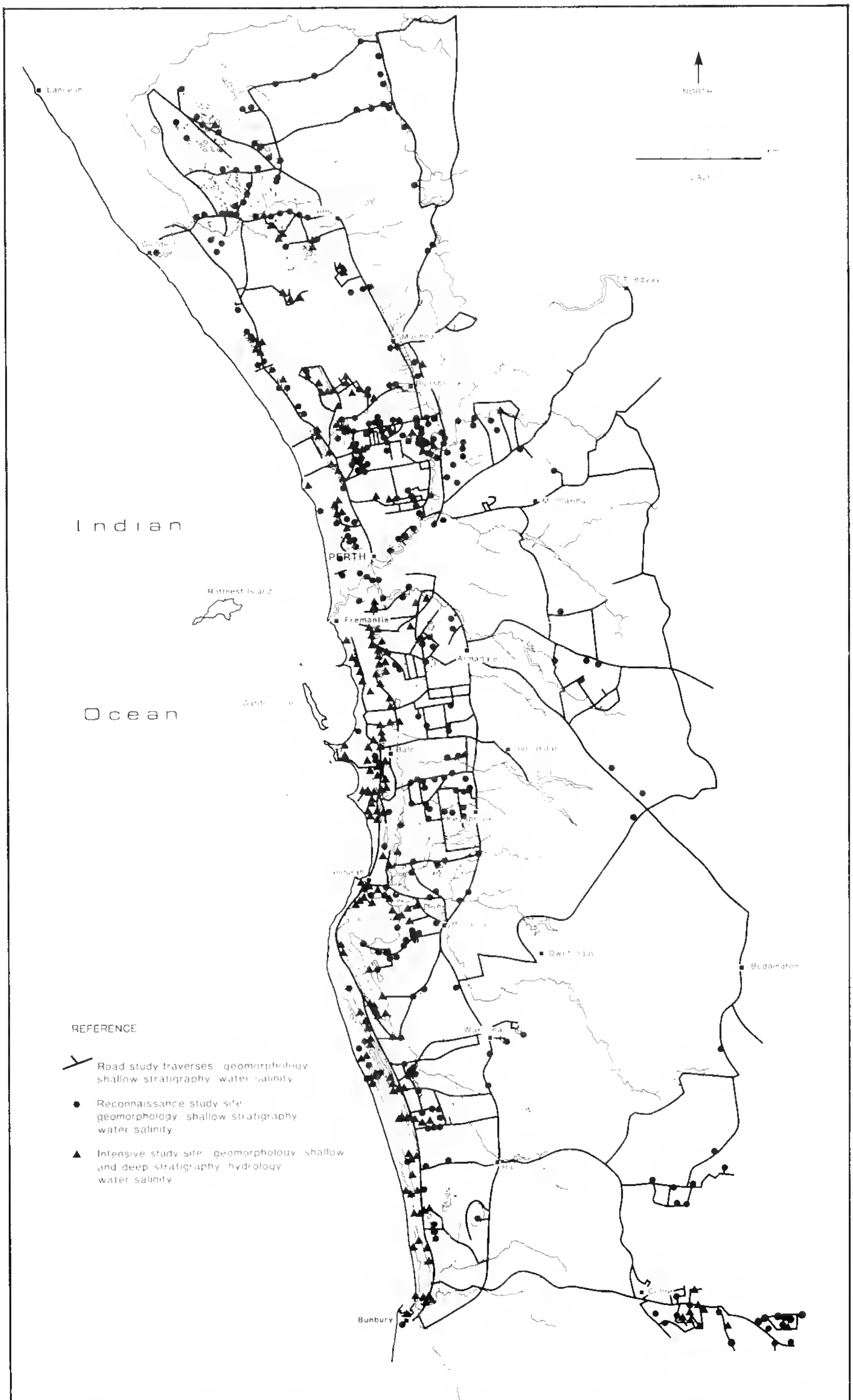


Figure 3 Study sites showing location of sampling sites and road transects. The road transects involved reconnaissance of every wetland that occurred along or in proximity to the road. Solid circles represent reconnaissance sites for investigation of geomorphology, shallow stratigraphy, soils and water quality. Solid triangles represent intensive study sites.

Table 1

WETLAND COMPONENTS FOR USE IN CLASSIFICATION

WET LAND

- Water Permanence
  - Permanently inundated
  - Seasonally inundated
  - Seasonally waterlogged
- Water Salinity
  - Fresh
  - Subsaline
  - Hyposaline
  - Mesosaline
  - Hypersaline
  - Brine
- Consistency of Water Salinity
  - Poikilohaline
  - Stasohaline
- Cross-Sectional Shape
  - Basin
  - Channel
  - Flat
- Size
  - Megascale
  - Macroscale
  - Mesoscale
  - Microscale
  - Leptoscale
- Plan Shape
  - Linear
  - Basins
    - Elongate
    - Irregular
    - Ovoid
  - Round
  - Channels
    - Straight
    - Sinuous
    - Anastomising
    - Irregular

Table 2

Description of wetland suites

Symbol	Name	Locations	Geomorphic Setting	Primary Wetlands	Description of Wetlands	Stratigraphy	Origin of Wetlands
Q1	Cooloongup suite	Rockingham area Shoalwater Bay & Bridivis	Quindalup Dunes/ Spearwood Unit contact & Quindalup Unit beachridge plain	Lakes	Mesoscale & macroscale elongate-ovoid, hyposaline, stasohaline	Carbonate mud overlying Becher sand or for Lake Richmond unfilled with sediment	Wetlands originated as barred oceanic basins as part of the prograding shoreline, now freshwater recharged
Q2	Becher suite	Between Safety Bay & Peelhurst, in the coastal dune area, locally at Preston	Quindalup Dunes, specifically the small scale plain of parallel beachridges	Sumplands & damplands	Leptoscale, linear freshwater, stasohaline, occur in linear chains	Humic sand or peat & thin carbonate mud overlying Safety Bay sand	Wetlands are a series of primary inter ridge depressions which intersect or lie close to the water table in a prograding coastal beachridge plain
Q3	Peelhurst suite	Narrow strip 3km long along the coast south of Becher Pt, locally along the west shore of L Walyungup & in isolated areas such as Whitfords cusp	Quindalup Dunes—specifically area of semi mobile dunes & blowout depressions	Sumplands & damplands	Leptoscale, ovoid, freshwater, stasohaline, oriented along southwest axes	Safety Bay Sand overlain by (carbonate) muddy sand	Wetlands are basins deflated to the level of the water table by prevailing onshore winds
Q/Y	Lake Preston suite	Situated parallel to coastline from Preston to Myalup	Lagoonal depression between Quindalup Dunes & Coongarillup Plain with the parallel ridges 20-40m above MSL	Lake	Megascale, linear mesosaline	Estuarine sediments bordered to west by Safety Bay Sand & to east by Tamala Limestone	Linear lake formed as lagoon behind retreating dune barrier
S1	Yanchep suite	Between Yanchep to the north & Kingsley to the south in a linear belt about 5km inland from the coast	Spearwood Dunes Unit-area of parallel, coastal dune ridges up to 40-60m above MSL, & associated segmented depressions	Lakes & sumplands	Microscale to macroscale mainly elongate to locally irregular; fresh, poikilohaline; forms a chain of wetlands	Thin layer of peat overlying grey to yellow sand	Wetlands occur in depressions between limestone ridges fed by discharge from limestone & groundwater table rise basins are young karst features
S2	Balcatta suite	In a 5km x 18km area north of the Swan R. estuary about 3km inland from the coast	Spearwood Dunes Unit/ area of hills & depressions within the limestone dune ridges	Sumplands [& lakes subsequent to clearing of vegetation eg Carine Swamp]	Microscale to macroscale irregular; fresh, stasohaline	Variable peat overlying yellow sand, to peat & clay overlying thick yellow sand	Wetlands occur in depressions between hills, possibly old (mature) karst features
S3	Coogee suite	In a linear belt 1-2km inland from the coast east of Woodman Pt	Spearwood Dunes Unit—inter dune ridge depression overlying limestone	Lakes & sumplands	Mesoscale to microscale irregular to elongate forming linear chains hyposaline to hypersaline, poikilohaline	Carbonate mud overlying limestone	Carbonate mud filled depressions now acting to pond meteoric water
S4	Stakehill suite	Linear belt extending from Wattleup to Mandurah	Spearwood Dunes Unit—ranging from ridges of limestone outcropping to ridges of yellow sand overlying limestone	Lakes & sumplands	Microscale to macroscale mainly elongate but locally irregular; forming a linear chain; subhaline poikilohaline	Carbonate mud & peat overlying yellow sand	Carbonate mud & peat filled depressions, probably originally karst depressions superimposed on palaeotopographic features

Y1	Clifton suite	Located parallel to coastline from Cape Bouvard to Burragenup	Yoongarillup Plain—inter-ridge depression between parallel ridges 20-60m above AHD	Lakes & sumplands	Mainly macroscale to megascale but ranging microscale to megascale linear chain of elongate to round wetlands variable salinity fresh to mesosaline	Thick carbonate mud & shelly mud overlying quartz sand & limestone	Linear inter ridge depressions along unconformity interfaces
Y2	Kooallup suite	Along a limestone ridge between Lake Preston & the hinterland, north of Myalup	Yoongarillup Plain	Sumplands	Mesoscale microscale round to irregular	Shelly carbonate mud overlying limestone	Holocene basins locally on former Pleistocene wetland depressions
SB1	Bibra suite	1. Linear belt extending south from Bidaminna to Caladenia Cave 2. Linear belt extending from Murdoch to Wellard in a N/S orientation approximately 5-7km east of the coast 3. Linear belt approximately 1km east of Harvey Estuary, including Lake Mealup & Lake McLarty	Spearwood Dunes & Bassendean Dunes contact depression. Continuous high dune ridges to the west & a series of discontinuous hollows & hills with lower relief to the east Lake McLarty	Lakes & sumplands in a north-south oriented chain	Mesoscale to macroscale mainly round but locally irregular fresh, poikilohaline	Mud peat or peaty sand overlying Bassendean Sand	Contact depressions with groundwater impounded against Spearwood Dune ridge
SB2	Hamden suite	Linear belt located 11-25km south of Harvey Estuary	Contact depression between Spearwood Dunes of yellow sand high ridge & Bassendean Dunes of low hills	Sumplands in a linear chain	Macroscale, ovoid to irregular fresh-water	Peaty sand overlying Bassendean Sand	Inter-ridge depression with groundwater impounded against Spearwood Dune ridge
B1	Lake Pinjar suite	Lake Pinjar area	Bassendean Dunes with higher undulating dunes on the western margin of the wetland	Sumpland	Megascale, ovoid, freshwater stasohaline	Quartz sand sheet overlying clay sheet on Bassendean Sand	Coalesced Bassendean Dune wetlands, meteoric water & discharge water from Gnangara Mound ponded by clay bed
B2	Gnangara suite	1. North of Beermullah Road between Duringen Swamp & Harris Swamp 2. South of Beermullah Road & north of Gingin Brook & west of Culcaderra Lake 3. East of Wanneroo including Lake Gnangara & Lake Jandabup	Bassendean Dunes with slightly higher undulating dunes on western margin of this area. Wetlands enclosed by saddles or ridges	Lakes & sumplands & occasional damplands	Macroscale through to microscale, round or ovoid freshwater stasohaline	Diatom mud peaty sand & clay overlying quartz sand. Hardpan (ferricreted qtz sand) at level of water table	Groundwater wetlands. Large lakes appear as coalesced smaller basins. Drainage is impeded by thin clay diatom mud or ferricrete layers superimposed on, or within the quartzose Bassendean sand
B3	Jandakot suite	1. Nine Mile Swamp area 2. Spade Lake to Caladenia Lake area 3. Bindian area 4. Gnangara Pine Forest area 5. Jandakot area 6. West Benger area	Bassendean Dunes—of low dunes & depressions	Damplands & sumplands	Microscale to meso-scale irregular closely-spaced & coalescing, freshwater, stasohaline	Peat or peaty sand or humic sand overlying quartz sand	Groundwater surfacing or near surface in depressions to develop water table basins
B4	Riverdale suite	1. West of Gingin, north & south of Gingin Brook 2. East Pinjar Lake area 3. Harvey River Flats area	Bassendean Dunes comprised of low regularly undulating dunes	Sumplands	Microscale to meso-scale irregular freshwater Closely spaced in linear parallel chains	Clay, peat or peaty sand overlying quartz sand	Wetlands occur in regularly spaced depressions as parallel microscale interdune swales to form linear, parallel chains, recharge by precipitation & groundwater rise, often maintained by ponding on a clay or peat bed

Symbol	Name	Locations	Geomorphic Setting	Primary Wetlands	Description of Wetlands	Stratigraphy	Origin of Wetlands
B/P1	Beermullah suite	West of Beermullah Lake & north of Beermullah Road.	Plain with very little topographic variation & some seepage lines but no established channels	Floodplain. A few shallow sumplands & disconnected drainage channels	Microscale channels, megascale floodplains	Clay	Discharge area for groundwater Precipitation is ponded
B/P2	Mungala suite	1. Warramboo Lake to Yeerealup Lake, west of Brand Hwy 2. Bambum, Nambung, Mungala area 3. Perth Airport surrounds including Wright Lake 4. Sevelj Road, west of North Dandalup R 5. A north-south band 5km east of Harvey Estuary 6. East of Harvey R, a u-shaped area between Buller Rd & Bristol Rd	Transition between Bassendean Dunes & Pinjarra Plain. Underlying stratigraphy is a complex of sands, clays, calcrete & laterite. Wetlands lie along depressions at the distributary ends of the creeks or adjacent to intermittent disconnected drainage channels	Lakes & sumplands floodplains, & creeks	Mesoscale, round, freshwater, poikilohaline lakes & hyposaline poikilohaline sumplands. Freshwater, poikilohaline flats. Freshwater drainage channels	Variable: clays to clay overlying quartz sand to quartz sand overlying laterite or calcrete	Alluvial fan distributaries of creeks terminate in wetlands already present in Bassendean sandplain, bringing water & sediment
B/P3	Muchea suite	1. Western margin of Whitfield Brook e.g. Six Mile Swamp 2. Western margin of Ellen Brook	Complex transition between Bassendean Dunes & Pinjarra Plain. Wetlands lie along the depressions at the base Bassendean Dunes & at the headwaters of the tributaries of creeks	Sumplands Floodplains	Microscale to mesoscale, irregular	Complex & variable pattern of quartz sand, clays, laterite & calcrete	Discharge of groundwater into basins, flats & creeks. Ponding of rainwater & groundwater occurs over impermeable sediments
B/P4	Bennett Brook suite	1. Balajura: In Bennett Brook area west of West Swan 2. Balannup: In Southern R area north of Forrestdale Lake 3. Yangedi: In Serpentine River area west of Serpentine township	Bassendean Dune—with microscale creeks	Sumplands creeks palusplains floodplains	Macrocale, irregular, subhaline poikilohaline sumplands. Microscale, meandering freshwater poikilohaline creeks. Macroscale, irregular to linear, freshwater plains	Quartz sands, or clay overlying quartz sand	Depressions which intersect the water table. Precipitation is ponded by clay lenses in the subsurface. Palusplains are situated between tributaries
B/P5	Benger Swamp suite	Benger Swamp area	Pinjarra Plain-Bassendean Dune transition; gently undulating area of alluvial fans dissected by channels, with a break in slope at the contact	Sumpland	Macroscale, round, freshwater	Peaty sand & peaty mud overlying quartz sand	Discharge basin at conjunction of alluvial fans
P1	Keysbrook suite	Alluvial fans along the foothills of the Darling Scarp occurring south of Forrestfield Lake & continuing as far south as Brunswick Junction	Alluvial fans & creeks of the Pinjarra Plain—gently undulating plain dissected by channels	Palusplains, floodplains, creeks	Palusplains are macroscale freshwater. Creeks are leptoscale to microscale, freshwater. Floodplains are microscale freshwater	Clay overlying lateritic clay & sand	Sediment discharge to develop alluvial fans; groundwater seepage, & surface runoff from the plateau & ponding of precipitation
E1	Moore River Estuary suite	Guilderton	Across the Quindalup Dunes & Spearwood Dunes	Estuary	Mesoscale, gradient from marine to hyposaline; poikilohaline; channel aligned east-west	Quartz sand & shelly sand	Aeolian barrier across river mouth

E2	Swan River Estuary suite	Swan River area between Fremantle & Guildford	Traversing 3 dune units: Quindalup, Spearwood & Bassendean. Flooded basins extend north & south of Swan River channel along depressions between Spearwood dune ridges & Bassendean Dunes.	Estuary	Megascale, poikilohaline, gradient from marine to hyposaline. Comprises bays, headlands, reaches, beaches, coves & river delta.	Mud & sand overlying quartz sand & limestone	Marine-inundated river valley which was receiving basin for Canning, Helen & Swan Rivers
E3	Peel-Harvey Estuary suite	Peel-Harvey estuary area	Traversing 3 dune units: Quindalup, Spearwood & Bassendean. Harvey Est is in elongated inter-ridge depression. Peel Est is circular located behind a limestone barrier	Estuary	Megascale, gradient from marine to hyposaline poikilohaline. Comprises reaches, bays, shelves, tidal deltas & channels & river deltas	Calcareous mud, muddy sand, quartz sand overlying quartz sand; limestone in some areas	Marine inundated valley system between two geomorphic units, & barrier lagoon
E4	Leschenault Inlet suite	Bunbury area	Occurs in interdune depression between Quindalup Dunes & Spearwood Dunes Comprises basins, flats, deltas	Estuary	Megascale, linear; gradient marine to hyposaline, poikilohaline	Calcareous mud, sand & muddy sand overlying quartz sand or limestone	Barrier-dune protected lagoon which is receiving basin for Collie & Preston Rivers
R1	Moore River suite	Moore River & Gingin Brook	Traversing the Swan Coastal Plain, incised channel with terraces	Creeks, river, floodplain	Microscale meandering channel; freshwater	Quartz sand	Fluvial incision; sedimentation; surface runoff
R2	Swan River suite	Swan River, Helena River, Canning River, Serpentine River, Dandalup River, Murray River, Harvey River, Wellesly River, Collie River & Brunswick River	Traversing the Swan Coastal Plain; incised channel alternates with braided shallow channel, terraces & large point bar deposits	River, floodplain	Microscale to mesoscale meandering & braided freshwater channel & floodplains	Alluvium of quartz sand & clay	Fluvial incision; sedimentation; surface runoff
R3	Ellen Brook suite	1. Gingin Brook south section, Moonda Brook Lennard Brook. 2. Ellen Brook area.	Pinjarra Plain	Creek, floodplain river	Microscale meandering & braided freshwater, poikilohaline channels. Many leptoscale tributaries join main channel over a short distance	Clays & sandy clays overlying laterite & sandstones	Fluvial incision; sedimentation; surface runoff
R4	Goegrup suite	Serpentine River section north of Peel Inlet to Karnup	Contact depression between Spearwood Dunes Unit & Bassendean Dunes Unit—along which Serpentine River meanders	River, floodplains, palusplains, creeks	Macroscale anastomosing hyposaline, poikilohaline, river. Palusplains are mesoscale freshwater. Floodplains are macroscale subhaline. Creeks are microscale, subhaline	Quartz sand with iron indurated hardpans	Fluvial incision; sedimentation; river has been impounded & water flow reduced
DP1	Red Gully suite	9km south of Moore River in Dandaragan Plateau	Dandaragan Plateau of gently undulating to flat surface with occasional broad gently sloping valleys alternating with incised creeks	Creeks & floodplains grading into sumplands	Meandering, leptoscale creek, freshwater. Mesoscale floodplains, freshwater which grade into mesoscale shallow sumplands	Quartz sand	Fluvial incision; surface runoff & depressions receiving ground water discharge from slopes
DP2	Coorang suite	Red Gully Road in Dandaragan Plateau	Gently undulating surface of Dandaragan Plateau with broad shallow depressions adjacent to valleys	Sumplands, floodplains, creeks	Mesoscale, ovoid sumplands. Mesoscale floodplains; Microscale, meandering, freshwater channels	Quartz sand sequence	Fluvial incision, broad valleys are the receiving basins for groundwater & precipitation

Symbol	Name	Locations	Geomorphic Setting	Primary Wetlands	Description of Wetlands	Stratigraphy	Origin of Wetlands
DP3	Clewley suite	1. North & south of Wannamal Road 2. Lake Nanger	Gently undulating surface of Dandaragan Plateau with low dunes & depression	Sumplands	Microscale, round & irregular sumplands grading into irregular floodplains & palusplains	Clay on sand	Impounded channels segmented to form basins
DP4	Mogumber suite	East Mogumber Road in Dandaragan Plateau	Gently undulating surface of Dandaragan Plateau with low dunes & shallow depressions	Sumplands	Macroscale, round sumpland associated with irregular mesoscale sumplands	Clay on sand	Large basin. (perhaps of coalesced smaller Clewley type basins)
DP/D	Wannamal Lakes suite	A linear belt from Mogumber to Wannamal on Dandaragan Plateau at base of Darling Scarp	Dandaragan Plateau & Darling Scarp contact. Gently undulating surface of Plateau	Sumplands	Macroscale linear, freshwater to hyposaline	Quartz sand	Discharge depression for groundwater from Darling Plateau & creeks from Darling Plateau
D1	Walyunga suite	1. Swan River 2. Wooroloo Brook 3. Helena River 4. Murray River 5. Western Plateau 6. Darling Scarp	Darling Plateau, steeply dissected valleys of laterite overlying preCambrian rocks, with incised channels	Creeks & rivers	Meandering, lepto-scale to microscale freshwater	Laterite or alluvium overlying Precambrian rocks	Fluvial incision sedimentation surface runoff channels
D2	Little Dardanup suite	1. North Dandalup 2. South Dandalup	Darling Plateau with incised channels alternating with channels with narrow floodplains or channel headwaters	Creeks, rivers, floodplains, palusplains, sumplands	Meandering, lepto scale to microscale freshwater channels. Microscale flood-plains & palus plains & sumplands	Laterite detritus or quartz sand & gravel overlying Precambrian rocks	Fluvial incision surface runoff in steeply sloped areas & ponded precipitation in areas with more gentle slopes or shallow depressions
D3	Harris River suite	1. Red Swamp Brook 2. Darkin River 3. Canning R East 4. Canning R 5. Yaganing Well 6. Yulyu 7. Kangaroo Gully 8. Harris River 9. Bingham River 10. Collie R (East)	Dissected Darling Plateau, steeply sided valleys with broad flat floors	Creeks, rivers, floodplains	Leptoscale to micro-scale creek or river, freshwater. Mesoscale flats freshwater.	Alluvium & quartz sand overlying Precambrian rocks	Fluvial incisions, sedimentation established valleys where channels have formed floodplains
D4	Nalyerin Lake suite	1. Manaring Lake near Chidlow 2. Nalyerin Lake 3. Yourdamung Lake near Harris River	Shallow upland depressions of the Darling Plateau	Sumplands	Round, mesoscale freshwater	Fills of sand with mud veneer	Sediment-filled impounded channels segmented to form basins. Perched water table. Discharge basin for surface runoff
D5	Hotham River suite	Hotham River	Darling Plateau with area of moderate slopes. Channels with alternating terraces, point bars & incised channels	River	Meandering mesoscale fresh to hyposaline	Alluvial fills	Fluvial incision & alluviation along established valley. Steep sides eroded to more gentle slopes
D6	Brockman River suite	1. Upper Avon River 2. Brockman River	Darling Plateau with steep valleys with moderate basal slopes & continuous terraces	Rivers	Meandering mesoscale, fresh-water to hyposaline	Alluvial fills	Established valley. Steep sides eroded to more gentle slopes. River incised, with present narrow flood-plain. Older flood plains become terraces
C1	Shotts suite	Collie area	Collie Basin. Gently undulating surface with linear shallow depressions which grade from flats to shallow basins	Sumplands creeks floodplains, Palusplains	Narrow, linear mesoscale fresh-water to subhaline	Sand sequence with thin mud veneers	Shallow valleys with intermittent surface water movement

Consanguinity

The concept of consanguinity intends to convey the notion of relationship between wetlands. In the geological literature the term consanguineous or consanguinity (Bates & Jackson 1980) is applied to materials. such as igneous or sedimentary rocks, where a genetic relationship exists; these materials may occur closely associated in space and time and commonly have a similar (geologic) occurrence and similar characteristics. In this paper the term is applied geomorphically with the same intention *ie* to denote relationship. Relationship in type and origin of wetlands, if it exists in a given area, is due to a similarity of causative factors and physical setting. Thus, if there is a similarity of climate, hydrology, geomorphology, geomorphic processes and developmental history, it may be expected that a suite of similar wetlands, or consanguineous wetlands, will result.

The criteria for assessing consanguinity are used on the assumption that causative factors are inter-related. For instance, geometry of wetlands is dependent upon geomorphic setting. Wetland size is related to ancestral geomorphology, wetland origin, evolutionary stage and amount of water. Water recharge and water maintenance mechanisms depend on wetland stratigraphy, geomorphic setting and present hydrologic regime. Wetland water salinity also depends on stratigraphy, geomorphic setting and present hydrologic regime. Wetland stratigraphy is related to wetland origin and vegetation, and vegetation depends on water depth, water permanence and soils. The criteria for identifying consanguineous wetlands are:

1 occurrence of wetlands in reasonable proximity to each other, although proximity alone may be no indication of wetland relationship as other factors such as geomorphic processes and hydrologic regime may become significant (Fig. 4A, B, D);

2 a similarity in wetland size and shape (Fig. 4A);

3A recurring pattern of similar wetland forms, i.e. a single wetland type predominates, or an assemblage of wetland types predominate (Fig. 4A, B, C);

or

3B heterogeneous pattern representing a spectral range of inter-related wetland forms, or an association of dissimilar but genetically related wetlands; these could result where there are similar underlying causative factors *cg* fluvial or hydrological processes (Fig. 4C, E, F);

4 similar stratigraphy and hence similar developmental history;

5 similarity of water salinity and its dynamics;

6 similarity of hydrological dynamics (*eg* whether wetlands are recharged and maintained by ponding, seepage, surface runoff, groundwater rise; Fig. 4F); and

7 similar origin *eg* karstification (Fig. 4D).

The criteria are applied in sequence as in a dichotomous key. Each criterion is applied in turn to progressively discriminate between wetland types to determine whether suites of wetlands are related. Criteria 1 to 3 can be applied from information obtained from aerial photographs and short field surveys; criteria 4 to 7 require increasing amounts of field information. Ideally all the criteria should be applied. In some instances the criteria relating to hydrology and salinity dynamics can only be fully applied after at least one year of seasonal sampling.

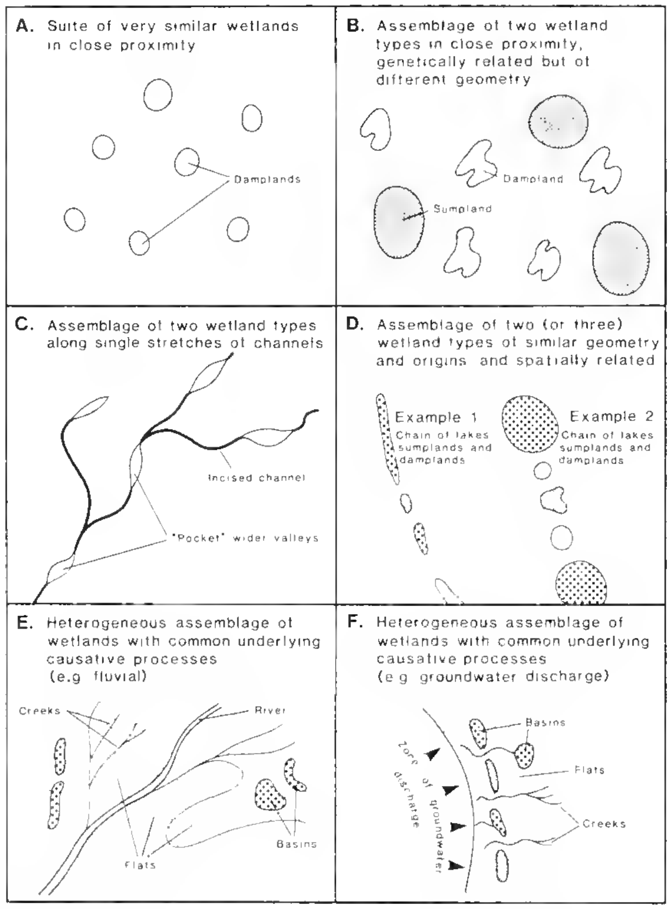


Figure 4 Idealized diagram illustrating range of possible types of wetland assemblages (or associations) that qualify to be termed consanguineous.

However, much information can also be obtained for criterion 5 from short survey water sampling, and for criterion 6 from the analysis of stratigraphy and geomorphology (*eg* water table depth, clay beds, peat beds, drainage lines, seepage lines, paperbark vegetated flats) within a context of local hydrologic and regional hydrological patterns.

At one extreme, a suite of consanguineous wetlands may incorporate a system of very closely related wetlands of similar size, shape, water characteristics, soils and stratigraphy. At the other extreme another suite of consanguineous wetlands may incorporate wetlands that differ in shape, stratigraphy or some other features, but represent a range of inter-related forms. These forms may be related only genetically, or may represent a spectral range of types (Fig.4). In other words, there may be local scale heterogeneity but the component wetlands of the consanguineous suite are inter-related and linked because of underlying causative factors. Riverine wetlands are an example of this.

Riverine wetlands, that is, those wetlands associated with fluvial areas, may consist of channels, bordering floodplains, extensive palusplains and occasional basins (sumplands and damplands), which alternate along the length of the system, all developed/evolved *in conjunction*, and superficially may be viewed as a group of heterogeneous wetlands. The whole wetland system, however, has developed as an internally heterogeneous but integrated unit.

Another example of internal heterogeneity within a consanguineous suite is afforded by groups of basin wetlands in geomorphologic settings in which a seasonal water table rise is the principal mechanism of water recharge. There may be a similarity of size, shape, soils and water quality between the wetlands, but because the undulating landsurface is situated at various heights above the water table there is developed a variable and random occurrence of lakes, sumplands and damplands. In this setting the wetlands differ only with respect to the longevity of their water, and so develop into an inter-related suite of consanguineous wetlands representing a spectral range from lakes through to damplands. Where inundation of a broad area of basins has occurred there may be coalescing of the smaller basins into a single large lake. Thus the spectral range may incorporate small damplands, sumplands and lakes with the occasional larger lake. In some examples, because the more inundated basins (lakes) have had a consistently different water history, their sediment margins and perhaps shape may have evolved differently and consequently the suite may consist of an assemblage of 2 wetland forms *e.g.* round medium to large scale lakes, and irregular medium scale sumplands and damplands.

An association of wetland types within a consanguineous suite may also occur in response to complex geomorphology and hydrology. For example an area with small scale variations from basins to flats and with small scale lenses of clay, sand, muddy sand, or calcrete, may produce a range of wetland types despite there being only one hydrological mechanism. Alternatively, a single geomorphic structure such as a flat may produce several wetland types in response to hydrological variations. Consanguinity thus is established on the basis that wetlands occur in the same vicinity with common or inter- related key features.

It should be noted that vegetation is not used as a criterion to identify consanguineous suites. Vegetation is considered to respond to underlying physical and chemical factors of a wetland and consequently it is not a primary causative factor of many wetland features. The influence of vegetation, however, is taken into account in that vegetation formations may produce peats and peaty soils which are considered in the analysis of stratigraphy of wetlands.

Markedly dissimilar wetlands of course are not consanguineous. For instance wetlands within the Bibra Lake chain are not consanguineous with those that form the Yanchep to Joondalup chain, in that they do not share similarity of size, shape, stratigraphy or mechanisms of water maintenance. In this case they do not even share similar origins.

Domains

The concept of domain in this paper intends to convey the notion of the occurrence, in discrete areas, of sets of consanguineous wetlands. The term is non-genetic but there is the inference that wetlands that occur in these discrete areas are influenced by similar major causative factors acting on the areas to produce consanguineous wetlands. Recognition of domains rests on identifying localities of consanguineous wetlands. The first step in this procedure is to identify wetlands in the same geomorphic setting. Thereafter it is necessary to isolate those tracts of landform that have wetlands with similar geometry, size, spacing and disposition and phototones on aerial photography. A domain boundary then is drawn around a set of consanguineous wetlands.

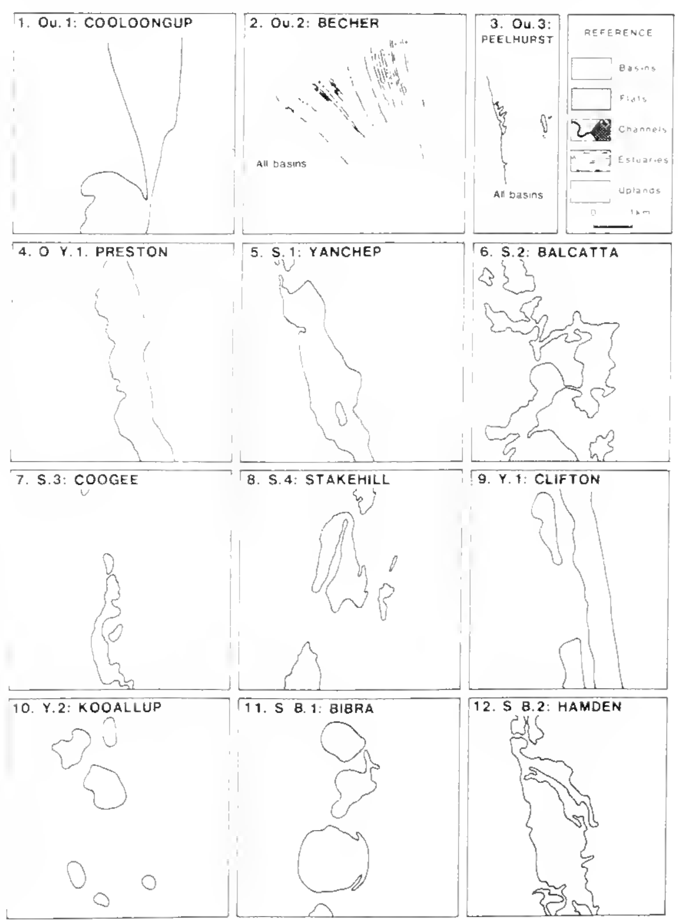
Results, this study

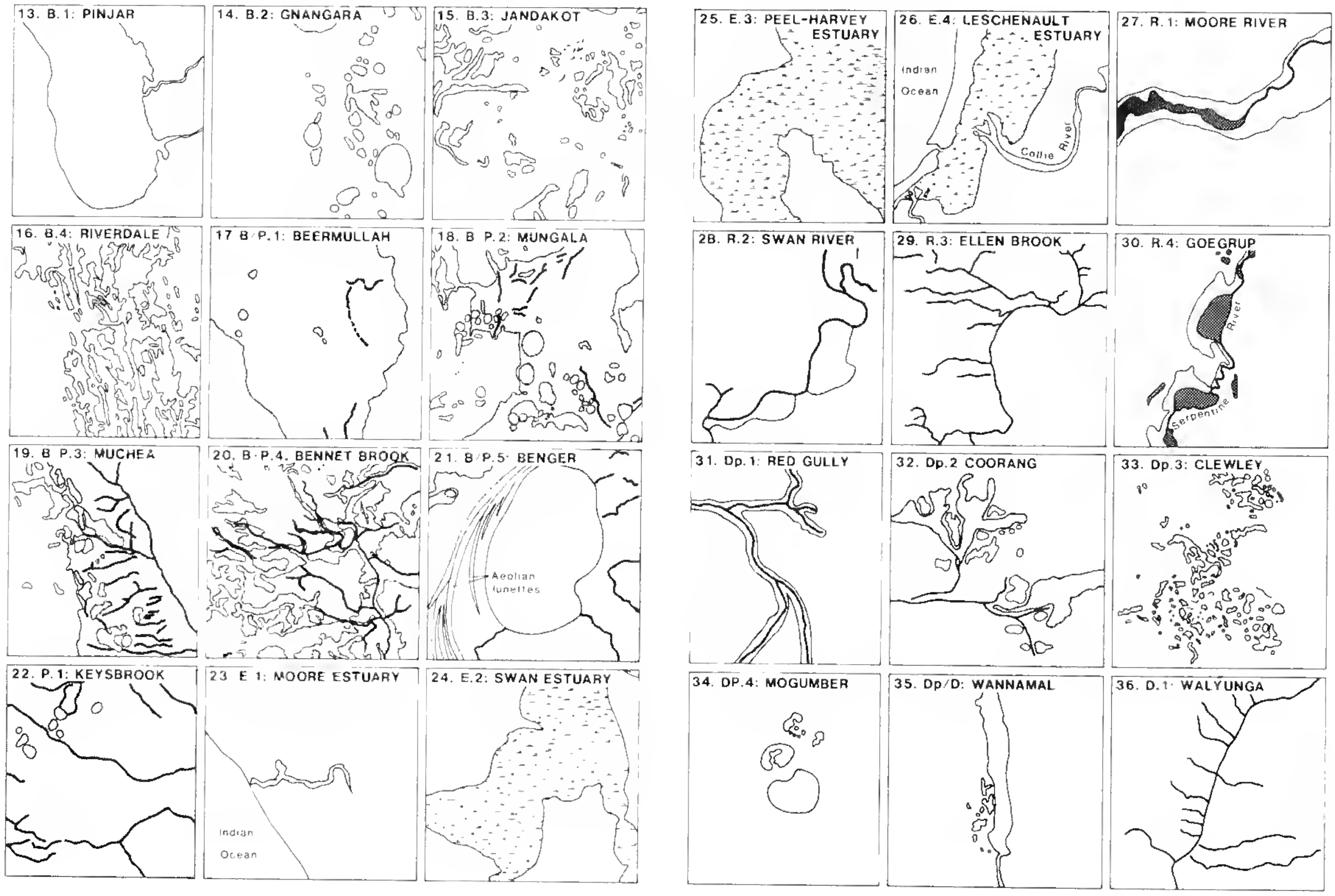
Types of consanguineous wetlands

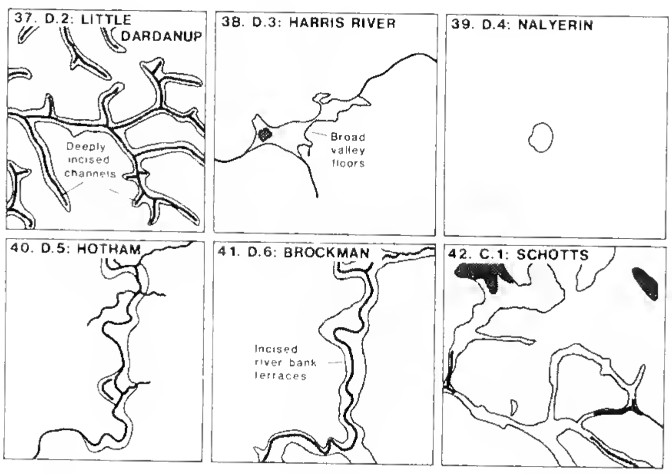
Based on the criteria described above, some 42 types of consanguineous wetland suites are recognized in the Darling System. These suites are named according to a geographic locality where the given suite is best developed. The consanguineous suites have been identified by their aerial photograph patterns within a context of geomorphic (landform) setting. Thereafter further differentiation of suites was based on field surveys to determine stratigraphy, hydrologic patterns, water quality, medium and small scale landform patterns and geomorphic processes. Examples of consanguineous wetland suites are illustrated in Fig. 5.

These examples are drawn from 10km x 10km areas and illustrate the range of wetland types, their size and shape and disposition within each of the type examples of a nominated wetland suite. As such, they provide pictorial information on the geometric features of each suite to enable ready discrimination between them. Table 2 presents detailed information on the characteristics of the various consanguineous wetland suites. As such, it provides more specific information of the features of each suite to enable further discrimination between them, if used in conjunction with the criteria.

Figure 5 Examples of the 42 consanguineous suites of wetlands (see Table 2 for description of the characteristics of each suite). Each of these maps are drawn from 10km x 10km areas on 1:60 000 aerial photographs.



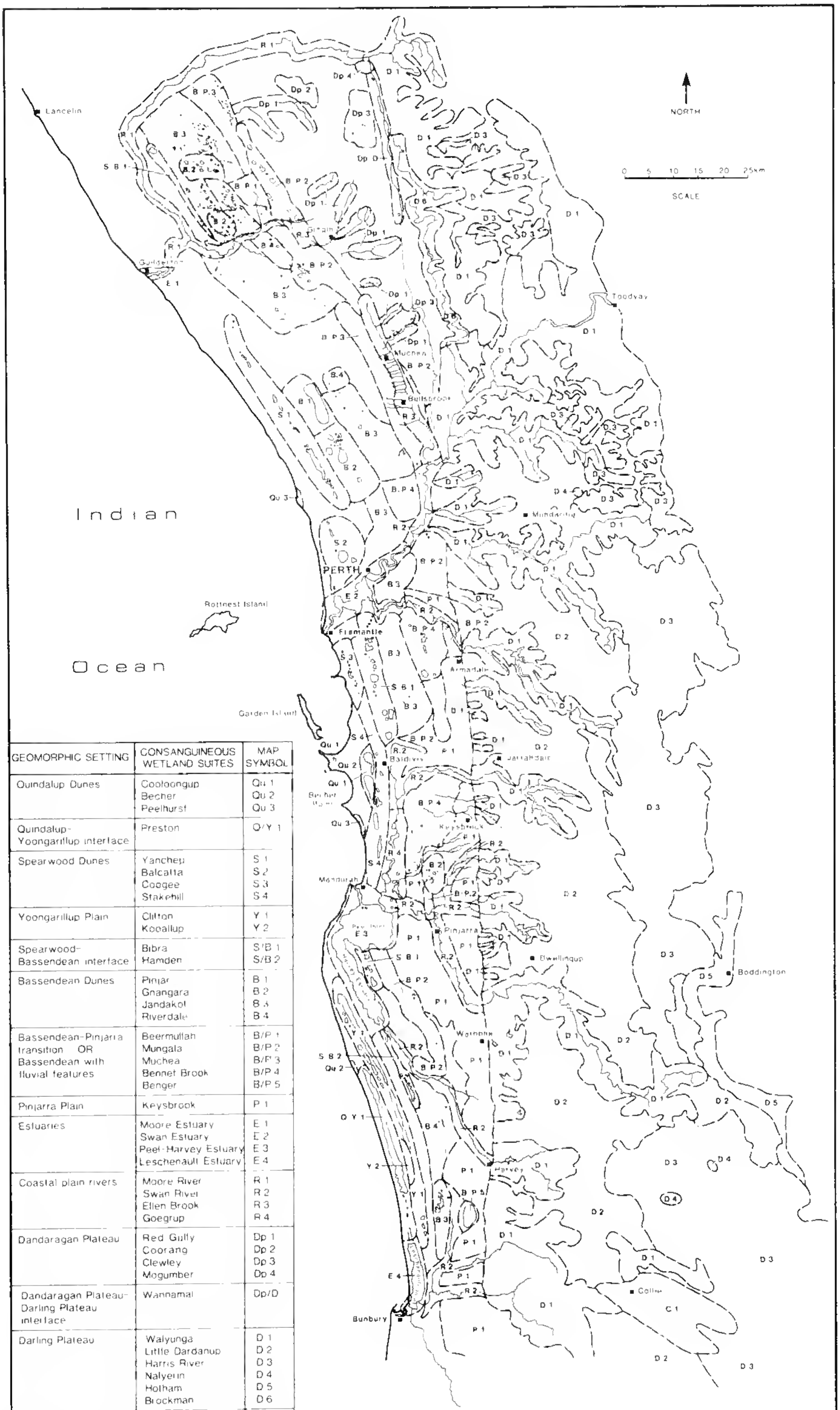




Many of the suites correlate strongly with the geomorphologic systems described by McArthur & Bettenay (1960), which is not surprising since the geometry and water characteristics of wetlands in general reflect geomorphic setting, geomorphic processes, hydrology and geomorphic history. Therefore the descriptions of the suites that follow are presented within the broader scale categories (or framework) of the large scale geomorphic units of the Darling System (= geomorphic elements of McArthur & Bettenay 1960). The wetland suites are described in groups representative of the geomorphic elements and the interfaces between the elements. In all, there are 14 broad categories of geomorphic elements and their interfaces that provide the framework for description of the consanguineous wetland suites; from west to east these are:

1. Quindalup Dunes
2. Quindalup Dunes-Spearwood Dunes, or Quindalup Dunes-Yoongarillup Plain interface.
3. Spearwood Dunes.
4. Yoongarillup Plain.
5. Spearwood Dunes-Bassendean Dunes interface.
6. Bassendean Dunes.
7. Bassendean Dunes/Pinjarra Plain transition zone, or Bassendean with fluvial features.
8. Pinjarra Plain.
9. Estuaries.
10. Coastal plain rivers
11. Darling Plateau.
12. Darling Plateau/Dandaragan Plateau interface.
13. Dandaragan Plateau.
14. Collie Basin

The wetland suites that are within these categories of geomorphic setting are listed in Table 3. The distribution of consanguineous wetlands in domains throughout the Darling System is shown in Fig. 6. An idealized illustration of the distribution of the consanguineous wetland suites in relationship to the regional-large scale geomorphic framework is shown in Fig. 7.



GEOMORPHIC SETTING	CONSANGUINEOUS WETLAND SUITES	MAP SYMBOL
Quindalup Dunes	Cooloongup	Qu 1
	Becher	Qu 2
	Peelhurst	Qu 3
Quindalup-Yoongarillup interface	Preston	Q/Y 1
Spearwood Dunes	Yanchep	S 1
	Balcatta	S 2
	Coogee	S 3
	Stakehill	S 4
Yoongarillup Plain	Clifton	Y 1
	Kooallup	Y 2
Spearwood-Bassendean interface	Bibra	S/B 1
	Hamden	S/B 2
Bassendean Dunes	Pinjar	B 1
	Gnangara	B 2
	Jandakot	B 3
	Riverdale	B 4
Bassendean-Pinjarra transition OR Bassendean with fluvial features	Beermullah	B/P 1
	Mungala	B/P 2
	Muchea	B/P 3
	Bennet Brook	B/P 4
	Benger	B/P 5
Pinjarra Plain	Keysbrook	P 1
Estuaries	Moore Estuary	E 1
	Swan Estuary	E 2
	Peel-Harvey Estuary	E 3
	Leschenault Estuary	E 4
Coastal plain rivers	Moore River	R 1
	Swan River	R 2
	Ellen Brook	R 3
	Goegrup	R 4
Dandaragan Plateau	Red Gully	Dp 1
	Coorang	Dp 2
	Clewley	Dp 3
	Mogumber	Dp 4
Dandaragan Plateau-Darling Plateau interface	Wannamal	Dp/D
Darling Plateau	Walyunga	D 1
	Little Dardanup	D 2
	Harris River	D 3
	Nalyerin	D 4
	Holham	D 5
	Brockman	D 6
Collie Basin	Scholls	C 1

Figure 6 Distribution of the consanguineous wetland suites in domains throughout the Darling System (see Table 3 for key symbols and relationship of suites to geomorphic setting).

Table 3:

List of suites & symbols correlated with main geomorphic units of the Darling System

Geomorphic setting	Abbreviation of geomorphic setting used in paper	Consanguineous wetland suites	Abbreviation used in paper (Fig. 6)	Map No. in Fig. 5
Quindalup Dunes	Qu	Cooloongup	Qu.1	1
		Becher	Qu.2	2
		Peelshurst	Qu.3	3
Quindalup-Yoongarillup Interface	Q/Y	Preston	Q/Y.1	4
Spearwood Dunes	S	Yanchep	S.1	5
		Balcatta	S.2	6
		Coogee	S.3	7
		Stakehill	S.4	8
Yoongarillup Plain	Y	Clifton	Y.1	9
		Kooallup	Y.2	10
Spearwood/ Bassendean Interface	S/B	Bibra	S/B1	11
		Hamden	S/B2	12
Bassendean Dunes	B	Pinjar	B1	13
		Gnangara	B2	14
		Jandakot	B3	15
		Riverdale	B4	16
Bassendean/ Pinjarra Transition or Bassendean with Fluvial Features	B/P	Beermullah	B/P1	17
		Mungala	B/P3	18
		Muchea	B/P2	19
		Bennett Brook	B/P4	20
		Benger	B/P5	21
Pinjarra Plain	P	Keysbrook	P1	22
Estuaries	E	Moore Estuary	E1	23
		Swan Estuary	E2	24
		Peel-Harvey Estuary	E3	25
		Leschenault Estuary	E4	26
Coastal Plain Rivers*	R	Moore River	R1	27
		Swan River	R2	28
		Ellen Brook	R3	29
		Goegrup	R4	30
Dandaragan Plateau	Dp	Red Gully	Dp1	31
		Coorang	Dp2	32
		Clewley	Dp3	33
		Mogumber	Dp4	34
Dandaragan Plateau Darling Plateau Interface	Dp/D	Wannamal	Dp/D	35
Darling Plateau	D	Walgunga	D1	36
		Little Dardanup	D2	37
		Harris River	D3	38
		Nalyerin	D4	39
		Hotham	D5	40
		Brockman	D6	41
Collie Basin	C	Schotts	C1	42

* Coastal plain rivers are equivalent, in part, to the Pinjarra Plain of McArthur and Bettenay (1960).

From Figure 7 it is evident that basin wetlands dominate the Quindalup, Spearwood, Yoongarillup and Bassendean units. Basins are replaced by channels and flats in the Pinjarra Plain unit and its transition with the Bassendean unit. The flats are often associated with channels and extend for some distance from them, but flats may also occur where channels are absent. Estuaries form discordant water bodies across the large scale geomorphic units. The scarp of the Darling Plateau is marked by incised microscale channels, which derive from one of five channel associations that dominate the Darling Plateau. This pattern is interrupted to the north of the system by the Dandaragan Plateau, which is dominated by basin wetlands that are very shallow and grade into flats associated with microscale creeks. The Collie Basin occurring in the south Darling Plateau provides another contrast with linear bifurcated shallow floodplains and sumplands.

The consanguineous wetland suites that are common and recur in domains throughout the Darling System include the Gnangara Suite, Jandakot Suite, Keysbrook Suite and wetlands of the Darling Plateau. Others are less common but nonetheless may still recur throughout the region (*eg* Nalyerin Suite), while others are regionally unique features (*eg* each of the estuaries, Kooallup Suite, and Yanchep Suite).

The consanguineous wetland suites of the Spearwood/ Yoongarillup Plain system, Quindalup Dunes, Quindalup Dunes- Spearwood Dunes interface and Collie Basin systems also tend to be unique and restricted to single domains. In the Spearwood Dune system north of Mandurah for instance, the system of wetlands differentiates into 4 separate suites, each occurring in its own single domain: the Yanchep Suite, the Balcatta Suite, the Coogee Suite and the Stakehill Suite, indicating that these wetlands although superficially similar, in that three of the four groups tend to be linear or chain systems, strictly are incomparable (Table 2). Each of the estuarine systems also qualifies to be recognised as separate suites and consequently each domain of the estuarine wetlands in the Darling System is regionally unique. The consanguineous wetland suites of the Bassendean Dunes, Bassendean Dunes/ Pinjarra Plain transition, the Pinjarra Plains and the Darling Plateau on the other hand are most common and recur throughout the Darling System in several separated domains.

Correlation with soil/landform units

The relationship (or correlation) between broad categories of wetlands of this study with the subdivisions of the Darling System into geomorphic elements is well pronounced. This relationship underscores the strong influence of large scale and medium scale landform associations and their geomorphic processes in determining type and distribution of consanguineous wetland suites. However, it is apparent that a number of separate domains can occur within a given geomorphic element. In the Quindalup Dunes there are 3 suites; the Spearwood Dunes and Yoongarillup Plain have 6, the Bassendean dunes have 4, and the Pinjarra Plain has only one. The Darling Plateau contains 5 suites. The occurrence of consanguineous wetland suites within each of the geomorphic elements and their interfaces is shown in Table 3.

The correlation of domains of consanguineous wetland suites with all of the landform soil units of Churchward & McArthur (1980) is not so well marked. Certainly in the Darling Plateau there is a strong correlation between the wetland suites D1, D2, D3, D4 and D5 with the landform-soil units of Churchward & McArthur (1980), but on the Swan Coastal Plain the finer scale subdivisions of the geomorphic elements such as Bassendean Dunes by Churchward & McArthur (1980) do not generally correlate with the distribution of the domains of this study. Some specific geomorphic units such as Quindalup Dunes have not been further subdivided into finer scale landform-soil units by Churchward & McArthur (1980) but this same unit differentiates readily into a number of different wetland domains. The subdivision of Karrakatta soil and Cottesloe soil associations within the Spearwood Dunes also does not correlate with any of the divisions of wetland domains identified in this study.

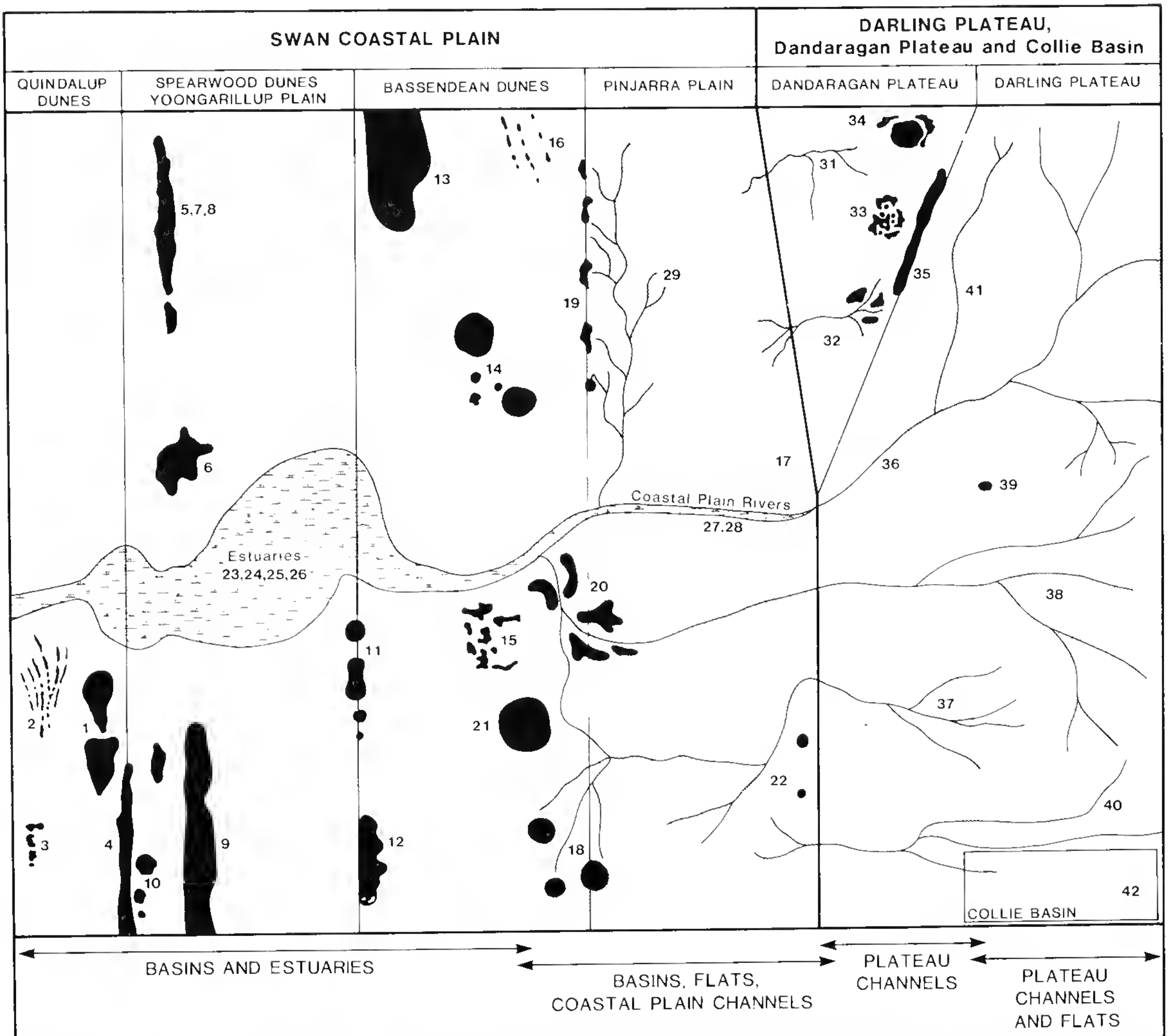


Figure 7 Idealized diagram showing wetland types and their distribution within the framework of regional to large scale geomorphic units of the Darling System. Numbers annotated against each wetland type relate to the consanguineous suites listed in Table 3. Wetland type 30, however, is not shown in this idealized diagram.

Discussion

The results of this paper may have direct application to regional studies and regional assessments of wetlands. The recognition of consanguineous suites of wetlands in discrete domains can provide a perspective of groups of wetlands as part of the Darling System. The conclusion that wetlands can be grouped as similar, related types may be used in comparative studies. The assessment of the representativeness of wetlands within a geomorphic unit or throughout the region, and the regional and local significance of wetlands, are important in comparative environmental studies, particularly in management of wetlands. This assessment can be based on domain information to determine whether a wetland type is widespread and common, or unique. Thus the approach using consanguineous wetlands and their occurrence in domains provides a primary basis for that comparison. The approach using domains can also form the basis for comparative studies of specific wetland features such as vegetation cover, faunal use of wetlands, and similarity of geomorphic and hydrologic processes that have formed and maintain wetlands, in that it may be assumed that the studies would be intentionally based specifically either on similar or dissimilar wetlands.

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